OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
ANALYSIS/MODEL COVER SHEET
Complete Only Applicable Items

1. QA: QA

2. ☒ Analysis — Check all that apply

Type of Analysis	☐ Engineering ☒ Performance Assessment ☐ Scientific
Intended Use of Analysis	☐ Input to Calculation ☐ Input to another Analysis or Model ☒ Input to Technical Document

Describe use:

This document is used to identify all features, events, and processes that could affect UZ flow and transport. Justification is provided for items excluded from TSPA.

3. ☐ Model — Check all that apply

Type of Model	☐ Conceptual Model ☐ Abstraction Model ☐ Mathematical Model ☐ System Model ☐ Process Model
Intended Use of Model	☐ Input to Calculation ☐ Input to another Model or Analysis ☐ Input to Technical Document

Describe use:

4. Title:

Features, Events, and Processes in UZ Flow and Transport

5. Document Identifier (including Rev. No. and Change No., if applicable):

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9. Checker	Richard Stover	WR Hunt for Richard Stover	3/14/00
10. Lead/Supervisor	James E. Houseworth	James E Houseworth	3/14/00
11. Responsible Manager	Clifford K. Ho	[illegible] for C.K. Ho	3/14/00

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OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
ANALYSIS/MODEL REVISION RECORD

Complete Only Applicable Items

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REV 00	Initial Issue

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ACRONYMS

AMR Analysis and Model Report

AP administrative procedure

CRWMS M&O Civilian Radioactive Waste Management System Management and Operating Contractor

DOE United States Department of Energy

DTN data tracking number

ECRB enhanced characterization of the repository block

ESF exploratory studies facility

FEP features, events, and processes

Ma million-year

NRC Nuclear Regulatory Commission

QAP Quality Administrative Procedure(s)

SZ saturated zone

SCFZ Solitario Canyon fault zone

TBV to be verified

TSPA total-system performance assessment

TSPA-SR total-system performance assessment – site recommendation

TSPA-VA total-system performance assessment – viability assessment

UZ unsaturated zone

VA viability assessment

WIPP Waste Isolation Pilot Project

YMP Yucca Mountain Site Characterization Project

1. PURPOSE

Unsaturated zone (UZ) flow and radionuclide transport is a component of the natural barriers that affects potential repository performance. The total system performance assessment (TSPA) model, and underlying process models, of this natural barrier capture some, but not all, of the features, events, and processes (FEPs) that are associated with this natural barrier. This analysis and model report (AMR) discusses all FEPs identified as associated with UZ flow and radionuclide transport. The purpose of this analysis is to give a comprehensive summary of all UZ flow and radionuclide transport FEPs and their treatment in, or exclusion from, TSPA models. This analysis will only acknowledge and refer to other documentation for FEPs treated explicitly in TSPA models, because detailed discussion of these FEPs exists in other analysis and model reports. Other FEPs may be screened out from treatment in TSPA by direct regulatory exclusion or through arguments concerning low probability and/or low consequence of the FEPs on potential repository performance. Arguments for exclusion of FEPs are presented in this analysis.

This report has been prepared in accordance with the development plan "Features, Events, and Processes in UZ Flow and Transport " (CRWMS M&O, 1999a).

2. QUALITY ASSURANCE

The quality assurance program is applicable to this report. The Performance Assessment Operations responsible manager has evaluated this activity in accordance with QAP-2-0, *Conduct of Activities*. The QAP-2-0 activity evaluation (CRWMS M&O 1999b) determined that the development of this AMR is subject to the *Quality Assurance Requirements and Description* (DOE 2000) requirements. This report is prepared in accordance with AP-3.10Q, *Analyses and Models*.

The unsaturated and saturated zone natural barriers have not been classified per QAP-2-3, *Classification of Permanent Items*. However the natural barriers have been classified by hydrogeologic units in the current project Q-List (YMP 1998). In this document, the following hydrogeologic units in the UZ were identified as important to waste isolation: Tiva Canyon Welded, Paintbrush Nonwelded, Topopah Spring Welded, Calico Hills Nonwelded. In addition, the saturated zone (SZ) was listed as a natural barrier important to waste isolation.

3. COMPUTER SOFTWARE AND MODEL USAGE

No models were developed as part of this AMR. Only results from upstream models were used in this analysis, and the relevant input data used in this analysis are listed in Section 4.1. The three software routines used in this analysis (as described below) are documented in accordance with AP-SI.1Q, *Software Management*.

A software routine, ptn_v1.f Version 1, was used to extract the coordinates of the Paintbrush Nonwelded hydrogeologic unit in four cross sections overlying the potential repository. The listing and documented verification of this software routine is given in Attachment IX. The results of this routine were verified by visual inspection. The listing of this routine along with the output generated by this routine may be found under DTN: MO9912SPAPTN01.006 in the Technical Data Management System.

A software routine, perch_ele.f Version 1, was used to extract the volumes of water in the fracture nodes of the perched water bodies as computed in the UZ flow model. The listing and documented verification of this software routine is given in Attachment X. The results of this routine were verified by visual inspection. The listing of this routine along with the output generated by this routine may be found under DTN: MO9912SPAPWI01.006 in the Technical Data Management System.

A software routine, pflux_rep.f Version 1**,** was used for calculating the repository-area percolation flux and its histogram (the latter function is not used in the present analysis). The listing and documented verification of this software routine is given in Attachment X. The results of this routine were verified by visual inspection. The listing of this routine along with the output generated by this routine may be found under DTN: MO9912SPAPWI01.006 in the Technical Data Management System.

4. INPUTS

4.1 DATA AND PARAMETERS

This summary analysis primarily relies on existing documentation for data and analysis. Data used directly for analyses in this report are given in Table 1.

Table 1. Input Data

Description/ Qualification Status	Data Tracking Number	Comments	Section Used
Borehole Locations/ Qualified	MO9907YMP99025.001	Used for locations of deep boreholes on the potential repository block	6.2.1
Coordinates for potential repository/ Not qualified	SN9907T0872799.001	Data for coordinates of potential repository used in cross-section plots for reference only.	6.3.5
Mesh/ Not qualified	LB990701233129.001	Mesh files used to identify coordinates of the PTn for cross-sectional plots.	6.3.5
Flow Field Simulations – used to compute perched water volumes and percolation flux at the potential repository./ Not qualified	LB990801233129.001	Present-day low infiltration; perched water model #1	6.7.9
	LB990801233129.002	Present-day low infiltration; perched water model #2	6.7.9

Table 1. Input Data (continued)

Description/ Qualification Status	Data Tracking Number	Comments	Section Used
Flow Field Simulations – used to compute perched water volumes and percolation flux at the potential repository./ Not qualified	LB990801233129.003	Present-day mean infiltration; perched water model #1	6.7.9
	LB990801233129.004	Present-day mean infiltration; perched water model #2	6.7.9
	LB990801233129.005	Present-day upper infiltration; perched water model #1	6.7.9
	LB990801233129.006	Present-day upper infiltration; perched water model #2	6.7.9
	LB990801233129.007	Glacial transition low infiltration; perched water model #1	6.7.9
	LB990801233129.008	Glacial transition low infiltration; perched water model #2	6.7.9
	LB990801233129.009	Glacial transition mean infiltration; perched water model #1	6.7.9
	LB990801233129.010	Glacial transition mean infiltration; perched water model #2	6.7.9
	LB990801233129.011	Glacial transition upper infiltration; perched water model #1	6.7.9
	LB990801233129.012	Glacial transition upper infiltration; perched water model #2	6.7.9

The data concerning borehole locations, repository footprint location, and unsaturated zone flow fields under various climate and perched water scenarios. These data are clearly relevant and appropriate information to help analyze the potential effects of boreholes and perched water on potential repository performance. The data concerning the geologic cross-sections is relevant to the question concerning episodic transient flow because the hydrogeologic units and their respective properties clearly play an important role in this process.

4.2 CRITERIA

Technical screening criteria used in this analysis are given in DOE's Interim Guidance (Dyer 1999). According to the DOE's Interim Guidance Section 102(j) (Dyer 1999), if the probability of occurrence for a FEP is less than 10^{-4} per 10^{4} years, then the FEP may be excluded from further consideration in the total system performance assessment. In this analysis, events with a probability of occurrence less than this magnitude are excluded from further consideration. In addition, FEPs may also be excluded from TSPA if they can be shown to have no significant effect on expected annual dose. There is no quantified definition of "significant effect" given in this guidance.

4.3 CODES AND STANDARDS

This AMR was prepared to comply with DOE's Interim Guidance (Dyer 1999) which specifies guidance to be used for evaluations in the absence of the NRC's final Yucca Mountain regulation. Subparts of this guidance that are particularly applicable to the data in this investigation include Subpart B, Section 15 (Site Characterization) and Subpart E, Section 114 (Requirements for Performance Assessment). Subparts applicable to models are outlined in Subpart E, Sections 114 (Requirements for Performance Assessment) and 115 (Required Characteristics of the Reference Biosphere and Critical Group).

5. ASSUMPTIONS

This AMR either identifies existing analyses that address specific FEPs for TPSA or provides justification for why specific FEPs are not addressed in TSPA. Any assumptions that are used in referenced analyses are not repeated here; the assumptions used in existing analyses and the bases for those assumptions are documented in the referenced analyses. Assumptions used to justify exclusion of specific FEPs are listed below along with the basis for these assumptions. The section numbers to which these assumptions apply are also identified.

Assumption 1 (Section 6.2.1)

Water entering a borehole that penetrates beyond the potential repository would tend to remain in the borehole or follow the borehole as a preferred pathway.

Basis: Flow will tend to follow the existing borehole pathway or enter fractures that are in communication with the borehole. All the boreholes are vertical or nearly vertical. Flow within the fractures will be dominated by the gravitational gradient, resulting in flow roughly parallel to the borehole. Any features that could result in significant lateral flow are rendered ineffective by the borehole. This assumption is reasonable and does not require further verification.

Assumption 2 (Section 6.2.6)

Boreholes drilled for the Yucca Mountain project are known and other undetected boreholes in or close to the repository block are very unlikely to exist at Yucca Mountain.

Basis: Drilling of boreholes for site characterization at Yucca Mountain are recorded (MO9906GP98410.000). Also, given the long and intensive site characterization activities at Yucca Mountain, the possibility of an undetected borehole near or in the potential repository block is very unlikely. This assumption is reasonable and does not require further verification.

Assumption 3 (Section 6.2.7)

Water movement in and around the emplacement drifts is primarily vertical relative to the length scale of the emplacement drifts.

Basis: The only known features at the site that could result in large-scale lateral diversion are the perched water bodies. These features are not present in the vicinity of the emplacement drifts. Therefore, the direction of water movement will be primarily controlled by the gravitational driving force, i.e. the flow will be predominantly vertical. This assumption is reasonable and does not require further verification.

Assumption 4 (Section 6.4.1)

Surface irregularities on the order of 10 cm developing over the course of 10,000 years will have a negligible effect on surface infiltration and therefore on potential repository performance.

Basis: Surface irregularities on the order of 10 cm exist for the present-day topographical conditions on the surface of Yucca Mountain. These irregularities are not specifically modeled in the surface infiltration model. Therefore, changes to the surface of this magnitude are not significant and changes of this magnitude to the surface topography are negligible. This assumption is reasonable and does not require further verification.

Assumption 5 (Section 6.5.1)

The effects of human activities on climate over the 10,000 year performance period are bounded by the changes in climate resulting from natural phenomena.

Basis: The effects of human activities on climate remain uncertain. However, repository performance is expected to be less favorable under the wetter, colder glacial climate. By stipulating an earlier start for the wetter and colder glacial climate (early in the 10,000 year regulatory period) , the potential effects of human activities are considered to be bounded. This assumption is reasonable and does not require further verification.

Assumption 6 (Section 6.6.1 and 6.6.3)

A build-up of gas pressure or trapping of intrusive gases in the repository environment will not occur over the 10,000-year performance period.

Basis: The host rock environment at Yucca Mountain is an unsaturated and fractured rock. The fractures are known to be highly permeable to the gas phase. Fracture are expected to remain permeable, even where thermo-chemical alteration occurs (CRWMS M&O 2000s; Section 6). Therefore, there is no plausible mechanism by which there could be a build-up of gas pressure or trapping and concentration of intrusive gases. This assumption is reasonable and does not require further verification.

Assumption 7 (Section 6.7.5)

Silicic magmatism is not expected at Yucca Mountain over the 10,000 year performance period.

Basis: Yucca Mountain lies outside the Timber Mountain caldera, the only source of silicic magmatism in the vicinity of Yucca Mountain over the last 11 million years (CRWMS M&O 1998a, Figure 3.5-2 and Table 3.2-3). This assumption is reasonable and does not require further verification.

Assumption 8 (Section 6.7.6)

The large hydraulic gradient is a result of durable differences of lithology, alteration history, and structural deformation rather than transient stress effects.

Basis: Observations of the geomechanical stress in the vicinity of Yucca Mountain (Stock and Healy 1988) do not support the hypothesis that the large hydraulic gradient results from a particular variation in stress conditions. Therefore, the cause of the large hydraulic gradient is likely to be a result of other factors such as lithology, alteration history, and structural deformation. This assumption is reasonable and does not require further verification.

Assumption 9 (Section 6.7.9)

A sudden release of all water and the associated radionuclides from the fracture domain of the perched water is a bounding scenario for the effects of perched water below the potential repository on performance.

Basis: The only water in the perched zone available for sudden release is the water residing in the fracture domain. The release of radionuclides from the matrix of the perched water would occur much more slowly. Therefore, any effects of perched water drainage below the repository would be bounded by this scenario. This assumption is reasonable and does not require further verification.

Assumption 10 (Section 6.3.8, 6.8.6)

Changes in aqueous geochemistry in the repository environment are dominated by thermal-chemical interactions associated with the potential repository.

Basis: With the exception of climate change, the potential repository is the only perturbation that will potentially affect the aqueous geochemistry of the unsaturated zone over the 10,000 year regulatory period. The assumption that the effects of climate change on the geochemistry will be smaller than the effects of the potential repository is based on the fact that temperature changes driven by the repository will be much larger than temperature changes that occur as a result of climate change. Also, the repository introduces a large number of new materials (some that are in substantial quantities) that will influence the geochemistry. Climate change may influence the concentrations of dissolved salts in water that percolates, but will not introduce new materials This assumption requires further verification and therefore is TBV.

Assumption 11 (Section 6.8.7, 6.8.8, and 6.8.10, 6.8.17, 6.8.18)

Results from the near-field, thermal-hydrologic-chemical coupled processes model can be used to bound the effects of similar coupled processes on far-field flow and radionuclide transport.

Basis: The effects of coupled processes in the near-field are expected to be more severe than in the far-field. This is due to the higher temperatures that will occur near the waste emplacement drifts, including boiling of the rock-water and the associated precipitation of minerals and condensation of dilute water. This assumption requires further verification and therefore is TBV.

Assumption 12 (Section 6.8.12)

The quantities of organic matter and microbes either emplaced or generated (through microbial growth processes) in the waste emplacement drifts are sufficiently small that they are unlikely to be of significance.

Basis: This assumption is based on the limited use of organic matter in the emplacement drifts, the limited quantities of natural organic matter available in the unsaturated zone, and the resulting limitation on organic material needed for microbial growth. This assumption requires further verification and therefore is TBV.

Assumption 13 (Sections 6.3.5, 6.8.4, 6.8.5)

Thermal-hydrologic flow processes will have a minimal effect on radionuclide transport.

Basis: The major effects of thermal-hydrologic flow processes will be near the emplacement drifts in the early part of the post-closure time period. Radionuclide releases will likely be after the main portion of the thermal pulse (after waste heat begins to dissipate) and a large part of the radionuclide transport process in the unsaturated zone will take place at locations outside the envelope of the main thermal-hydrologic effects. Thermo-hydrologic effects on the flow beneath the repository have been found to be small (CRWMS M&O 2000bb, Section 7). Therefore, the effects of thermal-hydrologic flow processes on radionuclide transport are expected to be negligible. These qualitative arguments require quantitative verification, therefore, this assumption is TBV.

Assumption 14 (Section 6.8.14)

Thermo-mechanical effects on hydrogeologic properties near waste emplacement drifts will be limited to a time period before any significant seepage into the drifts.

Basis: The main compressive stresses caused by thermo-mechanical effects will occur during the period when temperatures are increasing. Drift seepage is not expected during this time period when temperatures are increasing because water is boiled and removed as vapor flow from the vicinity of the waste emplacement drifts. The effects of thermo-mechanical stress around the waste emplacement drifts are expected to be small by the time water is present to seep into the drifts. This assumption requires further verification and therefore is TBV.

Assumption 15 (Section 6.7.1)

Mechanical stress around waste emplacement drifts after the thermal period are dominated by the existing in-situ stress created by the presence of the opening. Therefore, changes to mechanical stress due to fault movement around waste emplacement drifts is negligible.

Basis: Drift stability analyses have found that seismic activity has only a minor influence on rockfall in drifts (CRWMS M&O 2000d; Section 7). Therefore, the effects of fault movements on stress around the emplacement drifts are expected to be minor. This assumption requires further verification and therefore is TBV.

6. ANALYSIS/MODEL

There are 538 FEPs identified for unsaturated zone flow and transport from the Yucca Mountain Project (YMP) FEP database (CRWMS M&O 1999c). There is a large degree of overlap between these FEPs, and this overlap has been used to group FEPs into two broad categories, "primary" and "secondary" FEPs. Primary FEPs are those that capture the issues associated with secondary FEPs. In other words, the secondary FEPs are a subset of the primary FEPs.

There are 85 FEPs identified in the YMP FEPs data base (Freeze 1999) as "primary" FEPs for unsaturated zone flow and transport. Of these, four primary FEPs and their related secondary FEPs have been transferred to different FEPs analysis documents. YMP primary FEP 1.2.04.05.00, Magmatic Transport of Waste, plus 3 secondary FEPs are being treated in the Disruptive Events FEPs analysis. YMP FEPs 2.3.02.01.00, Soil Type, plus four secondary FEPs and 2.3.02.02.00, Radionuclide Accumulation in Soils, plus nine secondary FEPs, are being treated in the Biosphere FEPs analysis. Finally, YMP FEP 2.3.11.04.00, Groundwater Discharge to Surface, plus three secondary FEPs are being treated in the SZ FEPs analysis (CRWMS M&O 2000z; Section 6). Therefore, 81 primary FEPs are considered here.

The 81 primary FEPs considered in this analysis include an additional 434 "secondary" FEPs. The FEP disposition and screening arguments address both the primary and secondary FEPs. The FEPs are further divided into two broad categories: included and excluded FEPs. Included FEPs are those directly represented in TSPA models and process-level models that support TSPA. Included FEPs will be identified and briefly discussed, but the main description of theses FEPs are given in the reports describing the models used for or supporting TSPA. References to the appropriate reports will be given for these FEPs. Excluded FEPs are those not modeled in TSPA due to low probability or low consequence, as outlined in Section 4.2. In particular, low probability means that the occurrence of a FEP has a lower probability than 10^{-4} in 10^{4} years. Clearly, probability arguments could only potentially apply to FEPs that are low probability events and not to FEPs that represent existing site features or processes. Low consequence arguments in this analysis are based on the UZ subsystem performance. Thus, if a FEP can be shown to have minimal consequence on UZ subsystem performance, then it will also have a minimal consequence on total system performance. UZ subsystem performance is defined by the release of radionuclides at the water table. In some cases, the disposition of the FEP is split, i.e. some aspects are included and some aspects are excluded from TSPA. The rationale for exclusion of a FEP is given in the screening argument presented for each excluded (or partially excluded) FEP.

6.1 INCLUDED FEPS

Table 2 gives the FEP numbers for the YMP primary FEPs, the primary FEP titles, and some, but not all, of the secondary FEP titles for this category. Not all the secondary FEP titles are listed because many are identical, or nearly identical to the primary FEP title or to other secondary FEP titles under the same primary FEP. A listing of the description of each of the primary and secondary FEPs in this category is given in Attachment I. Some aspects of certain FEPs in some of the subsequent sections of this documents are also included, but these FEPs with mixed character (partially exclude/partially include) are treated in Sections 6.2 through 6.8.

Table 2. Included FEPS

YMP Primary FEP Number	Primary FEP Title	Secondary FEPs Titles
1.3.01.00.00	Climate change, global	• No ice age • Solar insolation • Exit from glacial/interglacial cycling • Intensification of natural climate change • Present-day climatic conditions • Seasonality of climate • Future climate conditions • Warmer climate – arid • Warmer climate – seasonal humid • Warmer climate – equable humid • Seasons • Temperature
1.3.07.02.00	Water table rise	None
2.1.08.01.00	Increased unsaturated water flux at the repository	• Water container is thermally quenched by rapid influx of water
2.1.08.02.00	Enhanced influx (Philip's drip)	None
2.2.03.01.00	Stratigraphy	• Mesozoic sedimentary cover • Permo-carboniferous trough • Brine reservoirs
2.2.03.02.00	Rock properties of host rock and other units	• Rock heterogeneity (host rock) • Low permeability domain effective hydraulic properties • Major water-conducting faults effective hydraulic properties • Properties of far-field rock
2.2.07.01.00	Locally saturated flow at bedrock/alluvium contact	None
2.2.07.02.00	Unsaturated groundwater flow in geosphere	• Unsaturated rock • Soil depth
2.2.07.03.00	Capillary rise	None
2.2.07.04.00	Focusing of unsaturated flow (fingers, weeps)	• Effects of preferential flow paths • Seeps and weeps form as a locally saturated flow system • Fault control of fluid entrance to and movement away from the repository • Fingering – contaminant transport in fingers in the unsaturated zone
2.2.07.08.00	Fracture flow in the unsaturated zone	• Extreme channel flow of oxidants and nuclides (in geosphere)

Table 2. Included FEPS (continued)

YMP Primary FEP Number	Primary FEP Title	Secondary FEPs Titles
2.2.07.09.00	Matrix imbibition in the unsaturated zone	• Resaturation due to matrix imbibition of episodic fracture flow
2.2.08.04.00	Redissolution of precipitates directs more corrosive fluids to containers	None
2.2.08.08.00	Matrix diffusion in geosphere	None
2.2.08.09.00	Sorption in UZ and SZ	• Far-field transport: sorption including ion exchange • Far-field transport: changes in sorptive surfaces • Anion exchange, general (in geosphere) • Soil pore water pH • Sorption (reversible and irreversible) • Sorption (nonlinear) • Saturation (of sorption sites) • Kinetics of sorption • Changes in sorptive surfaces
2.2.08.10.00	Colloidal transport in geosphere	• Far-field transport: transport of radionuclides bound to microbes • Colloid transport occurs in a carrier plume (in geosphere)
2.2.10.03.00	Natural geothermal effects	• Geothermal regime • Geothermal gradient effects
2.2.10.10.00	Two-phase buoyant flow / heat pipes	None
2.3.01.00.00	Topography and morphology	• Topography (current) • Topography (future)
2.3.11.01.00	Precipitation	• Precipitation, temperature and soil water balance • Flood (meteorology) • Extremes of precipitation, snow melt and associated flooding (meteorology)
2.3.11.02.00	Surface runoff and flooding	• Runoff (near-surface hydrology) • Flooding (near-surface hydrology) • Evapotranspiration (near-surface hydrology) • Flooding occurs in Drill Hole Wash and increases percolation below the wash • Faulting at surface produces a scarp causing an impoundment • River flooding
3.1.01.01.00	Radioactive decay and ingrowth	None

6.1.1 Climate Change, Global (1.3.01.00.00)

YMP Primary FEP Description: Climate change may affect the long-term performance of the repository. This includes the effects of long-term change in global climate (e.g., glacial/interglacial cycles) and shorter-term change in regional and local climate. Climate is typically characterized by temporal variations in precipitation and temperature.

Disposition: Include

Screening Argument: Global climate change is addressed in TSPA using a climate model based on paleoclimate information. That is, the record of climate changes in the past is used to predict the expected changes in climate for the future. The effects of seasonality is included in the climate model through the use of climate analogs with specific seasonal meteorological records. More specific information about the methods used to predict future climate change and the findings for the climate model are given in CRWMS M&O (2000a; Section 6). Climate modeling is incorporated into TSPA through the unsaturated zone flow fields that have different surface water infiltration as a result of different climates. A description of the modeling methods used for infiltration and how infiltration is affected by climate is given in CRWMS M&O (2000b; Section 6). The unsaturated zone flow model, which uses the infiltration results as upper boundary conditions for unsaturated zone flow calculations, is described in CRWMS M&O (2000c; Section 6). The incorporation of unsaturated zone flow fields into the TSPA are described in CRWMS M&O (2000w; Section 6). The secondary FEPs for climate change are included in the paleoclimate modeling method. Glaciation is brought up as an issue in some the secondary FEPs, which is also indirectly addressed by the paleoclimate model. Although glacial climates may occur over the next 10,000 years, glaciers are not expected to occur at Yucca Mountain over this time frame (USGS 2000a; Section 6). Therefore, glaciers are not part of the expected future climate conditions. Further discussion of glaciers are discussed in Sections 6.3.1 and 6.3.2. A similar argument is applicable to the question of warmer humid climates, which are also not found in the paleoclimate record for this location. The potential effects of human activity on climate are discussed in Sections 6.5.1 through 6.5.4.

6.1.2 Water Table Rise (1.3.07.02.00)

YMP Primary FEP Description: Climate change could produce increased infiltration, leading to a rise in the regional water table, possibly affecting the release and exposure pathways from the repository. A regionally higher water table and change in flow patterns might move discharge points closer to the repository, or flood the repository.

Disposition: Include

Screening Argument: The potential for water table rise due to climate change is included in TSPA calculations using a water table rise model based on paleoclimate data. The paleoclimate data suggests that the historical water table has not risen to the level of the potential repository (Forester et al. 1999; pages 46, 56). Water table changes are implemented in the TSPA by allowing the water table to change elevation instantaneously upon change in climate. Other aspects of this FEP (change in SZ flow patterns and SZ discharge points) are addressed in CRWMS M&O (2000z; Section 6).

6.1.3 Increased Unsaturated Water Flux at the Repository (2.1.08.01.00)

YMP Primary FEP Description: An increase in the unsaturated water flux at the repository affects thermal, hydrologic, chemical, and mechanical behavior of the system. Extremely rapid influx could reduce temperatures below the boiling point during part or all of the thermal period. Increases in flux could result from climate change, but the cause of the increase is not an essential part of the FEP.

Disposition: Include

Screening Argument: As discussed in Section 6.1.1, climate change is included in the TSPA through the infiltration boundary condition for the unsaturated zone flow model. Therefore changes in unsaturated zone flow in response to climate change are included. The effects of changes in unsaturated zone flow due to climate change are also included in the calculations for the thermal-hydrologic behavior of the potential repository system (CRWMS M&O 2000f; Section 6). The effects of transient flow driven by thermo-hydrologic processes are also included in TSPA calculations for drift seepage (CRWMS M&O 2000o; Section 6).

6.1.4 Enhanced Influx (Philip's drip) (2.1.08.02.00)

YMP Primary FEP Description: An opening in unsaturated rock alters the hydraulic potential, affecting local saturation around the opening and redirecting flow. Some of the flow is directed to the opening where it is available to seep into the opening.

Disposition: Include

Screening Argument: This FEP refers to the effects of a circular opening, such as a drift, on unsaturated flow in the vicinity of the drift and drift seepage for a homogeneous rock environment (Philip et al., 1989). These effects are directly included in the drift seepage model, which goes beyond homogeneous rock conditions to include the important effects of rock heterogeneity on seepage into waste emplacement drifts (CRWMS M&O 2000g; Section 6).

6.1.5 Stratigraphy (2.2.03.01.00)

YMP Primary FEP Description: Stratigraphic information is necessary information for the performance assessment. This information should include identification of the relevant rock units, soils and alluvium, and their thicknesses, lateral extents, and relationships to each other. Major discontinuities should be identified.

Disposition: Include

Screening Argument: This FEP is included in the unsaturated zone flow model through hydrogeologic property sets for flow, sorption data for radionuclide transport, and pore size characteristics affecting colloid transport. Aspects that affect hydrogeologic properties for flow are discussed in CRWMS M&O (2000h; Section 6 and 2000i; Section 6). Aspects that affect aqueous radionuclide transport properties are addressed in CRWMS M&O (2000j; Section 6). Aspects that affect colloid transport are addressed in CRWMS M&O (2000k; Section 6). Secondary FEPs concerning Mesozoic sedimentary cover and the Permo-Carboniferous Trough are specific issues related to the NAGRA (Swiss Nuclear Waste Disposal Agency) Kristalin-I site and are not applicable to Yucca Mountain. Similarly, the secondary FEP addressing brine reservoirs is a stratigraphic component important to the Waste Isolation Pilot Project (WIPP) project geology that is not applicable to Yucca Mountain.

6.1.6 Rock Properties of Host Rock and Other Units (2.2.03.02.00)

YMP Primary FEP Description: Physical properties such as porosity and permeability of the relevant rock units, soils, and alluvium are necessary for the performance assessment. Possible heterogeneities in these properties should be considered.

Disposition: Include

Screening Argument: This FEP is similar to the previous FEP on stratigraphy (Section 6.1.5) and the response in terms of treatment in TSPA is covered by that discussion. The question of rock heterogeneity is raised. The level of resolution for rock heterogeneity included in the models is based on the scale of the problem being addressed. For the unsaturated flow model, heterogeneity is modeled in terms of the sequence of hydrogeologic units and discrete faults (CRWMS M&O 2000c; Section 6 and CRWMS M&O 2000w; Section 6). For drift seepage a finer scale of resolution is needed and heterogeneity within the host rock unit is considered at the 0.5 m scale (CRWMS M&O 2000g; Section 6).

6.1.7 Locally Saturated Flow at Bedrock/Alluvium Contact (2.2.07.01.00)

YMP Primary FEP Description: In washes in arid areas, infiltration can descend to the alluvium/bedrock interface and then proceed down the wash at that interface as a saturated flow system distant from the surface and distinct from the local water table.

Disposition: Include

Screening Argument: The phenomenon of infiltration resulting in a saturated condition at the bedrock/alluvium contact, with subsequent lateral drainage of this water, is included in the infiltration model. The details concerning of how this is captured in the infiltration model is given in CRWMS M&O (2000b; Section 6).

6.1.8 Unsaturated Groundwater Flow in Geosphere (2.2.07.02.00)

YMP Primary FEP Description: Groundwater flow occurs in unsaturated rocks in most locations above the water table at Yucca Mountain, including at the location of the repository. See other FEPs for discussions of specific issues related to unsaturated flow. See FEPs 2.2.07.03.00 (capillary rise), 2.2.07.04.00 (focussing of unsaturated flow), 2.2.07.05.00 (effects of episodic infiltration), 2.2.07.07 (perched water), 2.2.07.08.00 (fracture flow), 2.2.07.09.00 (matrix imbibition), 2.2.07.10.00 (condensation zone forms), 2.2.07.11.00 (return flow from condensation zone), and 2.2.10.10.00 (buoyant flow / heat pipes).

Disposition: Include

Screening Argument: This FEP is included in the unsaturated zone process model for mountain-scale flow (CRWMS M&O 2000c; Section 6, CRWMS M&O 2000l; Section 6, and CRWMS M&O 2000w; Section 6) and for drift seepage (CRWMS M&O 2000g; Section 6 and CRWMS M&O 2000o; Section 6). The flow model is for three-dimensional, steady flow in a heterogeneous dual-permeability system including discrete fault zones. The flow fields generated by the process model are included directly in TSPA (for drift seepage and radionuclide transport) using a quasi-steady flow field approximation for climate change. The secondary FEP that addresses the potential for rock in the vicinity of the repository to become unsaturated is not relevant to Yucca Mountain because the potential repository is in the unsaturated zone. The effects of soil depth on unsaturated zone flow at Yucca Mountain are included in the infiltration model (CRWMS M&O 2000b; Section 6).

6.1.9 Capillary Rise (2.2.07.03.00)

YMP Primary FEP Description: Capillary rise involves the drawing up of water, above the water table or above locally saturated zones, in continuous pores of the unsaturated zone until the suction gradient is balanced by the gravitational pull downward. Capillary rise may provide a mechanism for radionuclides to reach the surface environment in locations where the water table is shallow.

Disposition: Include

Screening Argument: The effects of capillary forces on flow in the unsaturated zone are included directly in the process models for mountain-scale flow (CRWMS M&O 2000c; Section 6 and CRWMS M&O 2000w; Section 6) and drift seepage (CRWMS M&O 2000g; Section 6 and CRWMS M&O 2000o; Section 6). These effects include capillary rise. In the context of Yucca Mountain, this phenomenon refers to the fact that the zone of saturation will be slightly elevated above the level of zero capillary pressure.

6.1.10 Focusing of Unsaturated Flow (Fingers, Weeps) (2.2.07.04.00)

YMP Primary FEP Description: Unsaturated flow can differentiate into zones of greater and lower saturation (fingers) that may persist as preferential flow paths. Heterogeneities in rock properties, including fractures and faults, may contribute to focussing. Focussed flow may become locally saturated.

Disposition: Include

Screening Argument: The mountain-scale unsaturated zone flow model contains all the process mechanisms that could lead to flow focusing. However, the resolution of the mountain-scale model is limited to by the size of the girds. These grids are on the order of 100 m in horizontal dimension (CRWMS M&O 2000h; Section 6), therefore the ability to directly represent flow focusing in the process model is limited to the 100-meter scale or larger. The effects of averaging out smaller-scale flow variations is discussed in CRWMS M&O (2000l; Section 6). Faults are included in the unsaturated zone flow model as discrete features, therefore flow focusing in faults is included in the model (CRWMS M&O 2000c; Section 6 and CRWMS M&O 2000w; Section 6). The effects of the focused flow is included for radionuclide transport through the direct use of the process-model flow fields for calculating radionuclide transport in TSPA (CRWMS M&O 2000n; Section 6).

The process-level drift seepage model also contains process mechanisms that could lead to flow focusing. In this case the grid resolution is much finer, with grid dimension of 0.5 m (CRWMS M&O 2000g; Section 6). The drift-scale model relies on an upper boundary condition established by the mountain-scale flow model and therefore is limited in its ability to model focused flow. A drift seepage model abstraction is used in TSPA to compute seepage volumes based on the results of the process-level model. However, this model abstraction incorporates a calculation method to account for the effects of focused flow. See CRWMS M&O (2000o; Section 6) for further discussion of focused flow on drift seepage.

6.1.11 Fracture Flow in the Unsaturated Zone (2.2.07.08.00)

YMP Primary FEP Description: Fractures or other analogous channels act as conduits for fluids to move into the subsurface to interact with the repository and as conduits for fluids to leave the vicinity of the repository and be conducted to the SZ.

Disposition: Include

Screening Argument: This FEP is included in the process model for unsaturated zone flow at the mountain scale (CRWMS M&O 2000l; Section 6) and the drift scale (CRWMS M&O 2000g; Section 6). The conceptual model used is called the dual-permeability model in which the fractures and matrix are co-existing, interacting flow continua. The model allows for rapid flow and radionuclide transport through fractures with limited interaction with low-permeability matrix. See also section 6.1.8.

6.1.12 Matrix Imbibition in the Unsaturated Zone (2.2.07.09.00)

YMP Primary FEP Description: Water flowing in fractures or other channels in the unsaturated zone is imbibed into the surrounding rock matrix. This may occur during steady flow, episodic flow, or into matrix pores that have been dried out during the thermal period.

Disposition: Include

Screening Argument: Matrix imbibition is included in the process model for unsaturated zone flow at the mountain scale (CRWMS M&O 2000l; Section 6) and the drift scale (CRWMS M&O 2000g; Section 6). Matrix imbibition refers to the movement of water into the matrix due to capillary forces. This process affects the distribution of flow between fractures and matrix in a dual-permeability flow model for fractured rock. The influence of matrix imbibition on episodic flow is discussed in Section 6.3.5.

6.1.13 Redissolution of Precipitates Directs More Corrosive Fluids to Containers (2.2.08.04.00)

YMP Primary FEP Description: Redissolution of precipitates which have plugged pores as a result of evaporation of ground water in the hot zone, produces a pulse of fluid reaching the waste containers when gravity-driven flow resumes, which is more corrosive than the original fluid in the rock. See also FEP 2.2.07.11.00 for a discussion of return flow from condensation cap.

Disposition: Include

Screening Argument: This FEP concerns the coupled effects of thermal-hydrologic-chemical processes on seepage water. These effects are included in the process model and abstraction for seepage water chemistry (CRWMS M&O 2000s; Section 6 and CRWMS M&O 2000x; Section 6). The process model uses a two-dimensional drift-scale representation of the system that incorporate the effects of reactive transport in a dual-permeability flow and transport formulation. The reactive transport aspect of the model includes the feedback of precipitation/dissolution processes on hydrogeologic properties.

6.1.14 Matrix Diffusion in Geosphere (2.2.08.08.00)

YMP Primary FEP Description: Matrix diffusion is the process by which radionuclides and other species transported by advective flow in fractures or other pathways move into the matrix of the porous rock by diffusion. Matrix diffusion can be a very efficient retarding mechanism, especially for strongly sorbed radionuclides due to the increase in rock surface accessible to sorption.

Disposition: Include

Screening Argument: Diffusion of radionuclides between the fracture and matrix continua is a process that is included in the unsaturated zone transport model (CRWMS M&O 2000q; Section 6). The diffusion model used is based on a dual-porosity formulation in which the matrix water is stagnant. The abstraction for matrix diffusion includes the effects of partial saturation of the matrix, radionuclide sorption in the matrix, and finite spacing of fractures.

6.1.15 Sorption in UZ and SZ (2.2.08.09.00)

YMP Primary FEP Description: Sorption of dissolved and colloidal radionuclides can occur on the surfaces of both fractures and matrix in rock or soil along the transport path. Sorption may be reversible or irreversible, and it may occur as a linear or nonlinear process. Sorption kinetics and the availability of sites for sorption should be considered.

Disposition: Include

Screening Argument: Here we only comment on sorption in the unsaturated zone (UZ). Sorption is included in the TSPA model for unsaturated zone radionuclide transport as a linear equilibrium sorption (K_d) model (CRWMS M&O 2000q; Section 6). Sorption is only accounted for in the matrix continuum; there is no sorption modeled in the fracture continuum. Sorption characteristics of the rock minerals are assumed to be static in time. Distributions of sorption parameter values for each radionuclide/rock type combination (CRWMS M&O 2000j; Section 6) are sampled in the TSPA to account for the effects of natural variations in pore water chemistry and mineral surfaces on sorption. The effects of larger changes in geochemical conditions, due to repository perturbed conditions, are addressed in Sections 6.8.7, 6.8.8, 6.8.10, 6.8.11, and 6.8.16 through 6.8.18. The effects of nonlinear sorption are conservatively bounded by the minimum K_d approach (CRWMS M&O 2000j; Section 6). The question of saturation of sorption sites is addressed in CRWMS M&O (2000j; Section 6). If sorption sites are near saturation, the relationship of sorbed concentration versus solution concentration is expected to be nonlinear. In some cases, nonlinear sorption is observed (CRWMS M&O 2000j; Section 6). However, the use of a linear sorption approximation is expected to be conservative over the range of measured solution concentrations for sorption. Anion exclusion is implicitly accounted for in the matrix diffusion coefficients, but not in advective transport calculations.

6.1.16 Colloidal Transport in Geosphere (2.2.08.10.00)

YMP Primary FEP Description: Radionuclides may be transported in groundwater in the geosphere as colloidal species. Types of colloids include true colloids, pseudocolloids, and microbial colloids.

Disposition: Include

Screening Argument: Colloid transport is included in the TSPA model for unsaturated zone radionuclide transport. The process model for colloid transport is given in CRWMS M&O (2000k; Section 6). This model uses a two-dimensional discrete fracture model (DFM), in which the fracture and matrix are discretely represented. The effects of colloid filtration/resuspension are included as kinetic processes and colloid size exclusion from the matrix is also included in the process model. The abstraction of this process model in the particle tracking algorithm used for TSPA calculations is discussed in CRWMS M&O (2000q; Section 6). The abstraction is designed to work within the particle tracking algorithm used for solute transport. The model abstraction includes the filtration/resuspension process as an equilibrium process leading to an effective retardation for colloid movement. Radionuclide exchange between colloid and aqueous phases and size exclusion effects are also included in the colloid transport abstraction model. The potential effects of microbes on radionuclide transport, including colloidal transport, is addressed in Section 6.8.12 The potential effects of a carrier plume on radionuclide transport is addressed in Section 6.8.7.

6.1.17 Natural Geothermal Effects (2.2.10.03.00)

YMP Primary FEP Description: The existing geothermal gradient, and spatial or temporal variability in that gradient, may affect groundwater flow in the unsaturated and saturated zones.

Disposition: Include

Screening Argument: Natural geothermal effects are included in the models of thermo-hydrologic processes used to describe the effects of waste heat in the potential repository (CRWMS M&O 2000f; Section 6) The thermal-hydrologic models contain the natural geothermal gradient in its initialization. This gradient is specified by the ground surface temperature, the water table temperature, and the thermal conductivities from layer-to-layer. The results of these models are used in the TSPA through a model abstraction (CRWMS M&O 2000r; Section 6).

6.1.18 Two-Phase Buoyant Flow / Heat Pipes (2.2.10.10.00)

YMP Primary FEP Description: Heat from waste generates two-phase buoyant flow. The vapor phase (water vapor) escapes from the mountain. A heat pipe consists a system for transferring energy between a hot and a cold region(source and sink respectively) using the heat of vaporization and movement of the vapor as the transfer mechanism. Two-phase circulation continues until the heat source is too weak to provide thermal gradients required to drive it. Any alteration of the rock adjacent to the drift produces may include dissolution which maintains the permeability necessary to support the circulation (as inferred for some geothermal systems).

Disposition: Include

Screening Argument: The process mechanisms for heat pipe formation and evolution are included in the thermal-hydrologic process models used to describe the effects of waste heat in the potential repository system (CRWMS M&O 2000f; Section 6). The results of these models are used in the TSPA through a model abstraction (CRWMS M&O 2000r; Section 6).

6.1.19 Topography and Morphology (2.3.01.00.00)

YMP Primary FEP Description: This category includes FEPs related to the topography and surface morphology of the disposal region. Topographical features include outcrops and hills, water-filled depressions, wetlands, recharge areas and discharge areas. Topography, precipitation, and surficial permeability distribution in the system will determine the flow boundary conditions, i.e. location and amount of recharge and discharge in the system.

Disposition: Include

Screening Argument: Current topography is included in the infiltration model CRWMS M&O (2000b; Section 6). This is incorporated into the TSPA through the unsaturated zone flow fields that use the infiltration model results as upper boundary conditions (CRWMS M&O 2000c; Section 6 and CRWMS M&O 2000w; Section 6). Changes to the topography due to erosion or glaciation are addressed in Sections 6.4.1 and 6.3.2 respectively.

6.1.20 Precipitation (2.3.11.01.00)

YMP Primary FEP Description: Precipitation is an important control on the amount of recharge. It transports solutes with it as it flows downward through the subsurface or escapes as runoff. The amount of precipitation depends on climate.

Disposition: Include

Screening Argument: Precipitation is included in the infiltration model CRWMS M&O (2000b; Section 6). This is incorporated into the TSPA through the unsaturated zone flow fields that use the infiltration model results as upper boundary conditions (CRWMS M&O 2000c; Section 6 and CRWMS M&O 2000w; Section 6).

6.1.21 Surface Runoff and Flooding (2.3.11.02.00)

YMP Primary FEP Description: Surface runoff and evapotranspiration are components in the water balance, together with precipitation and infiltration. They can also be important vehicles for the dispersion of contaminants. Surface runoff produces erosion, and can feed washes, arroyos, and impoundments, where flooding may lead to increased recharge.

Disposition: Include

Screening Argument: Surface runoff is included in the infiltration model CRWMS M&O (2000b; Section 6). This is incorporated into the TSPA through the unsaturated zone flow fields that use the infiltration model results as upper boundary conditions (CRWMS M&O 2000c; Section 6 and CRWMS M&O 2000w; Section 6). The effects of flooding over the locations of sealed boreholes is addressed in Section 6.2.1 The effects of faulting and creation of surface impoundments are addressed in Sections 6.7.2 and 6.7.7.

6.1.22 Radioactive Decay and Ingrowth (3.1.01.01.00)

YMP Primary FEP Description: Radioactive decay of the fuel in the repository changes the radionuclide content in the fuel with time and generates heat. Radionuclide quantities in the system at any time are the result of the radioactive decay and the growth of daughter products as a consequence of that decay. The type of radiation generated by the decay depends on the radionuclide, and the penetrating distance of the radiation depends on the type of radiation, its energy and the surrounding medium.

Disposition: Include

Screening Argument: The effects of radioactive decay and ingrowth are included in the model for radionuclide transport in the unsaturated zone (CRWMS M&O 2000q; Section 6). Simple radioactive decay is computed using the process-level mathematical model. The chain-decay (ingrowth) algorithm is a based on a mathematical approximation that is shown to compare well with the process-level chain-decay mathematical model (CRWMS M&O 2000q; Section 6).

6.2 BOREHOLES AND REPOSITORY SEALS

This group of FEPs are generally excluded from the TSPA calculation, with some exceptions noted in the screening arguments presented here. These FEPs concern the effects of boreholes and repository drifts as pathways for fluid and radionuclide migration. The implicit assumption to be used in the TSPA is that boreholes are sealed so that the borehole region is indistinguishable from the natural rock in terms of fluid flow and radionuclide transport. Although boreholes will be sealed, the specific properties of the seals and their evolution over time are not accounted for in the flow and transport modeling. Similarly, repository drifts will be assumed to be sealed such that liquids or gases cannot migrate between emplacement drifts (other than through geosphere pathways). Arguments are presented here to demonstrate that the potential effects of leakage of the borehole or repository seals have a negligible effect on the potential performance of the repository.

Table 3 gives the FEP numbers for the YMP primary FEPs, the primary FEP titles, and some, but not all, of the secondary FEP titles for this category. Not all the secondary FEP titles are listed because many are identical, or nearly identical to the primary FEP title or to other secondary FEP titles under the same primary FEP. A listing of the description of each of the primary and secondary FEPs in this category is given in Attachment II.

Table 3. Included/Excluded FEPs: Repository and Borehole Seals

YMP Primary FEP Number	Primary FEP Title	Secondary FEPs Titles
1.1.01.01.00	Open site investigation boreholes	• Exploratory boreholes (sealing) • Investigation boreholes • Underground boreholes
1.1.01.02.00	Loss of integrity of borehole seals	• Investigation borehole seal failure and degradation • Borehole seal failure
1.1.02.01.00	Site flooding (during construction and operation)	• Repository flooding during operation
1.1.04.01.00	Incomplete closure	• Non-sealed repository • Abandonment of unsealed repository • Unsealed boreholes and/or shafts
1.1.11.00.00	Monitoring of repository	• Monitoring and remedial activities • Post-closure monitoring
1.4.04.02.00	Abandoned and undetected boreholes	• Exploratory borehole creates flow pathway • Container lies in the trace of an old borehole • Waste-induced borehole flow (in waste and EBS) • Flow through undetected boreholes • Natural borehole fluid flow • Borehole induced mineralization • Borehole-induced geochemical changes
2.1.05.01.00	Seal physical properties	• Seal geometry • Consolidation of seals • Shaft and tunnel seals
2.1.05.02.00	Groundwater flow and radionuclide transport in seals	None
2.1.05.03.00	Seal degradation	• Seal evolution • Seal failure • Degradation of hole and shaft seals • Shaft or access tunnel seal failure and degradation • Degradation of hole and shaft seals • Loss of integrity of shaft or access tunnel seals • Mechanical degradation of seals • Chemical degradation of seals

6.2.1 Open Site Investigation Boreholes (1.1.01.01.00)

YMP Primary FEP Description: Site investigation boreholes that have been left open, improperly sealed, or reopened for some reason, could modify flow and transport properties and produce enhanced pathways between the surface and the repository.

Disposition: Exclude effects of deep boreholes on the basis of low consequence. Include effects of ground-support boreholes on drift seepage.

Screening Argument: Boreholes could act as enhanced pathways for the movement of water between the surface and the potential repository and the movement of radionuclides dissolved in water between the potential repository and the water table. The question to be addressed is whether or not the effects of such enhanced pathways could have a significant impact on repository performance.

Table 4. Deep Boreholes in or Close to the Potential Repository Block

Borehole Identifier	Elevation (feet)	Depth (feet)	Easting (feet)	Northing (feet)
USW G-1 (in block)	4350.150	6000.00	561001.062	770501.625
USW G-4 (close to block)	4166.130	3001.00	563081.750	765807.500
USW H-3 (close to block)	4866.470	4000.00	558451.875	756542.000
USW H-4 (close to block)	4096.170	4004.00	563911.375	761644.500
USW H-5 (in block)	4851.350	4000.00	558908.438	766634.125
USW NRG-6 (close to block)	4092.120	1100.00	564187.000	766726.500
USW NRG-7a (close to block)	4207.170	1513.00	562984.000	768880.125
USW SD-12 (in block)	4342.820	2166.30	561605.625	761956.562
USW SD-7 (in block)	4472.000	2675.10	561240.250	758949.875
USW SD-9 (in block)	4272.640	2223.00	561818.000	767998.500
USW UZ-1 (in block)	4424.730	1270.00	560221.562	771277.375
USW UZ-14 (in block)	4425.400	2207.00	560141.562	771309.812
USW UZ-6 (in block)	4925.170	1887.00	558325.000	759730.188
USW UZ-6s (close to block)	4949.160	519.00	558050.688	759909.312
USW WT-2 (close to block)	4268.230	2060.00	561924.000	760661.562
USW SD-6 (in block)	4905.400	2541.00	558652.625	762290.500

DTN: MO9907YMP99025.001

Only boreholes within or close to the potential repository block are important to the performance of the UZ. This is due to the predominantly vertical flow paths through the unsaturated zone. Boreholes that are laterally offset from the potential repository block will not influence water movement to the waste emplacement drifts or radionuclide transport from the waste emeplacement drifts to the water table. There are 10 deep boreholes in the potential repository block and 6 deep boreholes near the potential repository block (DTNs: MO9907YMP99025.001, SN9907T0872799.001) . There are an additional 18 shallow neutron boreholes in the potential repository block (not included in the Table 4). All but one of these 18 neutron boreholes have depths less than 100 feet. One neutron borehole (USW-UZ-N27) is about 202 feet deep (DTN: MO9907YMP99025.001), however this hole lies on the western boundary of the emplacement area. Any percolation coming through these pathways should be homogenized by matrix flow in the underlying Paintbrush nonwelded hydrogeologic unit.

With regard to water movement between the surface and the potential repository, two important facts are relevant to the deep boreholes. First, most of these holes penetrate the unsaturated zone between the surface and the water table and second, none of the boreholes will intercept waste emplacement drifts. Therefore water entering these boreholes would tend to continue flowing through these holes to the water table (Assumption 1). A few of the deep boreholes are only partially penetrating. However, none of the (deep) boreholes in the potential repository block terminates above potential waste emplacement locations. Therefore, if these boreholes have any effect, they should act as conduits that conduct flow away from potential waste emplacement zones.

The other aspect of this problem is the movement of dissolved radionuclides and radionuclides associated with mobile colloids between the potential repository and the water table. The movement of radionuclides could potentially be enhanced through the borehole pathways. However, unless there is significant lateral diversion of transport, radionuclides are unlikely to enter the borehole pathways because of the lateral offset between the boreholes and the waste emplacement locations. A potential "worst case scenario" is the migration of perched water through the borehole pathways. A bounding calculation was performed in which radionuclides in the perched water were immediately transported to the water table (see Section 6.7.9). This calculation shows that the perturbation in radionulcide mass flux at the water table due to a sudden release of radionuclides in the perched water zones is small. Therefore, the potential effects of these boreholes on repository performance, even if the borehole seals should fail completely, are expected to be negligible.

Test boreholes drilled in the underground facility are all relatively short (they remain within the TSw hydrogeologic unit) and are only present in access and observation drifts, not in the waste emplacement drifts. Due to the highly fractured nature of the host rock, the presence of these short boreholes is expected to have negligible effects on radionuclide transport. A large number of boreholes are expected to be drilled in the waste emplacement drifts for installation of rock bolts for ground support. The effects of these boreholes are considered in the drift seepage process model (CRWMS M&O 2000g; Section 6).

6.2.2 Loss Of Integrity Of Borehole Seals (1.1.01.02.00)

YMP Primary FEP Description: Degradation and/or failure of seals in site investigation boreholes could alter the flow path between the surface and the repository and possibly create a short-circuit to the biosphere.

Disposition: Exclude effects of deep boreholes on the basis of low consequence. Include effects of ground-support boreholes on drift seepage.

Screening Argument: This FEP is similar in content to the one discussed in Section 6.2.1. The effects of water movement between the surface and the potential repository, the movement of radionuclides between the potential repository and the water table, and the effects of short test boreholes drilled in the underground facility were found (see Section 6.2.1) to be negligible with respect to repository performance. Therefore, these aspects are excluded on the basis of low consequence. The effects of ground-support boreholes are considered in the drift seepage process model (CRWMS M&O 2000g; Section 6).

6.2.3 Site Flooding (During Construction and Operation) (1.1.02.01.00)

YMP Primary FEP Description: Flooding of the site during operations could introduce water into the underground, and could affect long-term performance.

Disposition: Exclude on the basis of low probability.

Screening Argument: This FEP describes an issue related to preclosure operations. The occurrence of a preclosure events will be addressed in operational plans approved by NRC. Any further deviation not addressed would be a noncompliance and require action based on NRC and EPA advice and consent. Therefore, this FEP is excluded from TSPA.

6.2.4 Incomplete Closure (1.1.04.01.00)

YMP Primary FEP Description: Disintegration of society could result in incomplete closure, sealing and decommissioning of the disposal vault.

Disposition: Exclude effects of deep boreholes on the basis of low consequence. Include effects of ground-support boreholes on drift seepage.

Screening Argument: This FEP is similar in content to the ones discussed in Sections 6.2.1 and 6.2.7. The effects of water movement between the surface and the potential repository, the movement of radionuclides between the potential repository and the water table, and the effects of short test boreholes drilled in the underground facility were all found (see Section 6.2.1) to be negligible with respect to repository performance. The effects of drift seals on water or gas movement through the drifts were also assessed (Section 6.2.7) to have a negligible effect on repository performance. Therefore, these aspects are excluded on the basis of low consequence. The effects of ground-support boreholes are considered in the drift seepage process model (CRWMS M&O 2000g; Section 6).

6.2.5 Monitoring of Repository (1.1.11.00.00)

YMP Primary FEP Description: This category contains FEPs related to monitoring that is carried out during or after operations, for either operational safety or verification of long-term performance. Monitoring boreholes could provide enhanced pathways between the surface and the repository.

Disposition: Exclude on the basis of low consequence.

Screening Argument: This FEP is similar to the ones discussed in Sections 6.2.1 and 6.2.7. Monitoring is a preclosure operational issue. The occurrence of a preclosure events will be addressed in operational plans approved by NRC. Any further deviation not addressed would be a noncompliance and require action based on NRC and EPA advice and consent. The effects of monitoring excavations, i.e., short boreholes in the vicinity of waste emplacement drifts, are excluded based on low consequence. Test boreholes drilled in the underground facility are all relatively short (they remain within the TSw hydrogeologic unit) and are only present in access and observation drifts, not in the waste emplacement drifts. Due to the highly fractured nature of the host rock, the presence of these short boreholes is expected to have negligible effects on postclosure repository behavior.

6.2.6 Abandoned and Undetected Boreholes (1.4.04.02.00)

YMP Primary FEP Description: Abandoned and undetected boreholes could provide pathways for preferential flow and, potentially, contaminant transport between any intersected zones. These flow connections could also result in geochemical changes in the receiving hydrologic units.

Disposition: Exclude on the basis of low probability.

Screening Argument: This FEP is similar to the one discussed in Section 6.2.1. As for the FEP in Section 6.2.1, we are only concerned with boreholes in or close to the potential repository block. However, the issue of abandoned, undetected boreholes is raised in this FEP. Boreholes drilled in the course of site-characterization activities are assumed to be identified. Boreholes drilled by others prior to the Yucca Mountain Site Characterization Project may exist. However, given the extensive site characterization carried out at Yucca Mountain for over 15 years (DOE 1998; p. 1-1), the possibility of undetected boreholes at the site is very low (Assumption 2).

6.2.7 Seal Physical Properties (2.1.05.01.00)

YMP Primary FEP Description: Physical properties of the seals emplaced in the access ramps, ventilation shafts, and exploratory boreholes may affect the long-term performance of the disposal system. These properties include the location of the seals (and the openings they seal), and the physical and chemical characteristics of the sealing materials.

Disposition: Exclude on the basis of low consequence.

Screening Argument: The host rock in the potential repository is highly fractured; hence seals for repository access drifts are of little consequence for water movement in the repository environment. There is only a small driving force for water to move along the relatively horizontal access drifts or emplacement drifts. Water is expected to move in a vertical flow pattern through the waste emplacement drifts relative to the length scale of these drifts, with some flow diversion around the drifts due to the capillary barrier effect (Assumption 3). The ventilation shafts do connect to access drifts at the waste emplacement level, and therefore represent pathways for water to enter the waste emplacement drifts. For postclosure, the ventilation shafts will be backfilled. These ventilation shafts are expected to behave in a manner similar to smaller fault features with respect to flow from the surface to the potential repository. The shafts will be located such that they are not subject to flooding (CRWMS M&O 2000aa, Section 1.2.2.1.3). Therefore, the quantity of water available to flow through the ventilation shafts is limited to rainfall and should not exceed infiltration that occurs in smaller fault features. Although fault features are suspected pathways for rapid migration of water from the surface to the potential repository (as observed from ^{36}Cl measurements), the amount of water that can by-pass matrix flow in the Paintbrush nonwelded hydrogeologic unit is a only a small fraction of the total infiltration (CRWMS M&O 1997, Section 6.12.4). Similarly, flow through the backfilled ventilation shafts should have a large component of matrix flow, greatly reducing the chance of transient water pulses penetrating from the surface to the waste emplacement drifts. Therefore, the effects of the ventilation shafts on flow from the surface to the potential repository is expected to be negligible. Gas flow could potentially move through the drifts, so drift seals could affect the nature of this flow. However, the fractured nature of the host rock ensures that gas will be able to move between drifts if there is a driving force for this flow pattern. Given these conditions, the effects of seals in the repository access drifts and ventilation shafts are expected to have very little effect on the movement of gas or water in the repository environment and therefore have little effect on repository performance. The effects of borehole seal failure properties can be excluded on the basis of low consequence, as discussed in Section 6.2.1.

6.2.8 Groundwater Flow and Radionuclide Transport in Seals (2.1.05.02.00)

YMP Primary FEP Description: Groundwater flow in through seals in the access ramps, ventilation shafts, and exploratory boreholes could affect long-term performance of the disposal system. Radionuclide transport through borehole seals below the repository should be considered.

Disposition: Exclude on the basis of low consequence.

Screening Argument: This FEP is similar in content to the ones discussed in Sections 6.2.1 and 6.2.7. The effects of water movement between the surface and the potential repository, the movement of radionuclides between the potential repository and the water table, and the effects of short test boreholes drilled in the underground facility were all found (see Section 6.2.1) to be negligible with respect to repository performance. The effects of drift seals on water or gas movement through the drifts were also assessed (Section 6.2.7) to have a negligible effect on repository performance. Therefore, this FEP is excluded on the basis of low consequence.

6.2.9 Seal Degradation (2.1.05.03.00)

YMP Primary FEP Description: Degradation of seals in the access ramps, ventilation shafts, and exploratory boreholes could modify flow and transport properties, including enhanced flow and transport between the surface and the repository . Possible mechanisms for seal degradation include: chemical alteration from water interactions, wetting associated with condensation, and thermally -induced stress-strain changes.

Disposition: Exclude on the basis of low consequence.

Screening Argument: A detailed analysis of different seal failure mechanisms is irrelevant because the effects of borehole seal failure, discussed in Section 6.2.1, and drift seal failure, discussed in Section 6.2.7, are found to have negligible effects on repository performance. Borehole and drift seals are not relied upon for repository performance. Therefore, this FEP is excluded on the basis of low consequence.

6.3 EXTREME CLIMATE / EPISODIC TRANSIENT FLOW

This group of FEPs are generally excluded from the TSPA calculation, although there are some exceptions as noted in the FEP screening arguments given below. These FEPs concern the effects of climate and episodic transient flow on hydrologic conditions, flow, and radionulcide transport in the unsaturated zone. In TSPA, episodic (or short duration) transient flows are ignored and an average steady flow is assumed to be representative. The rationale for this assumption is discussed below. Longer-term changes in climate are included in TSPA using a quasi-steady flow assumption, i.e. that the flow fields instantaneously adjust to steady conditions for a given climate (infiltration). However certain aspects of climate discussed in this section are excluded based on low probability.

Table 5 gives the FEP numbers for the YMP primary FEPs, the primary FEP titles, and some, but not all, of the secondary FEP titles for this category. Not all the secondary FEP titles are listed because many are identical, or nearly identical to the primary FEP title or to other secondary FEP titles under the same primary FEP. A listing of the description of each of the primary and secondary FEPs in this category is given in Attachment III.

Table 5. Included/Excluded FEPs: Climate and Episodic Transient Flow

YMP Primary FEP Number	Primary FEP Title	Secondary FEPs Titles
1.3.04.00.00	Periglacial effects	• Permafrost • Accumulation of gasses under permafrost • Frost weathering • Solifluction • Tundra climate
1.3.05.00.00	Glacial and ice sheet effects, local	• Glacial erosion/sedimentation • Glacial-fluvial erosion/sedimentation • Ice sheet effects (loading, melt water recharge) • Isostatic rebound
1.3.07.01.00	Drought / water table decline	• Desert and unsaturation • Dust storms and desertification
1.4.01.01.00	Climate modification increases recharge	• Climate modification causes perched water to develop at base of Topopah Spring unit • Climate modification causes perched water to develop above repository • Climate modification raises water table • Climate modification raises water table to flood repository
2.2.07.05.00	Flow and transport in the UZ from episodic infiltration	• Episodic infiltration enhances colloid transport
2.2.07.06.00	Episodic / pulse release from repository	None
2.2.07.07.00	Perched water develops	None
2.3.11.03.00	Infiltration and recharge (hydrologic and chemical effects)	• Freshwater intrusion (in geosphere) • Equilibrated flow system • Draining flow system

		• Surface water chemistry • Runoff is intercepted by wash terraces • Runoff to washes infiltrates and maintains a zone of higher flux to the unsaturated zone • Flow in ephemeral streams tends to be in channels and is a source of recharge • Changes in groundwater recharge and discharge • Coupling of surface water flow to climate/hydrologic modeling system

6.3.1 Periglacial Effects (1.3.04.00.00)

YMP Primary FEP Description: This category contains FEPs related to the physical processes and associated landforms in cold but ice-sheet-free environments. Permafrost and seasonal freeze/thaw cycles are characteristic of periglacial environments.

Disposition: Exclude on the basis of low probability.

Screening Argument: This FEP refers to climate conditions that could produce a cold, but glacier-free environment. Results of such a climate could include permafrost (permanently frozen ground). Some consequences of such a condition identified in the secondary FEPs are enhanced erosion due to the freeze/thaw cycle and the trapping of gases in or near the potential repository. Paleoclimate records indicate that such conditions are extremely unlikely to occur at Yucca Mountain over the next 10,000 years (USGS 2000a; Section 6). Therefore, this FEP is excluded from TSPA on the basis of low probability.

6.3.2 Glacial and Ice Sheet Effects, Local (1.3.05.00.00)

YMP Primary FEP Description: This category contains FEPs related to the effects of glaciers and ice sheets occurring within the region of the repository, including direct geomorphologic effects and hydrologic effects. These effects include changes in topography (due to glaciation and melt water), changes in flow fields, and isostatic depression and rebound.

Disposition: Exclude on the basis of low probability.

Screening Argument: This FEP refers to the effects of glaciers and ice sheets. Paleoclimate records indicate that such conditions are extremely unlikely to occur at Yucca Mountain over the next 10,000 years (USGS 2000a; Section 6). Therefore, this FEP is excluded from TSPA on the basis of low probability.

6.3.3 Drought / Water Table Decline (1.3.07.01.00)

YMP Primary FEP Description: Extreme climate change could produce an extended drought, leading to a decline in the water table in the saturated zone and affecting the release and exposure pathways from the repository.

Disposition: Exclude on the basis of low consequence.

Screening Argument: This FEP refers to the effects of a climate change that leads to much drier climate conditions. Some of the consequences of this type of climate change are water table decline and desertification of the surface environment. However, the Yucca Mountain region is already a desert environment, and future climates are only expected to have increased precipitation. In any case, a decline in the water table and lower infiltration rates would only enhance the unsaturated zone as a barrier to radionuclide movement. Therefore, it is conservative to exclude this FEP.

6.3.4 Climate Modification Increases Recharge (1.4.01.01.00)

YMP Primary FEP Description: Climate modification causes an increase in recharge in the Yucca Mountain region. Increased recharge might lead to increased flux through the repository, perched water, or water table rise.

Disposition: Exclude effects of perched water below repository on the basis of low consequence. Include the effects of increased flux through repository and water table rise.

Screening Argument: This FEP is related to the ones discussed in Sections 6.1.2 and 6.3.7. The potential for water table rise due to climate change is included in TSPA calculations using a water table rise model based on paleoclimate data. As discussed in Section 6.1.2, water table changes due to climate are not expected to reach the potential repository. Water table changes are implemented in the TSPA by allowing the water table to change elevation instantaneously upon change in climate. Another aspect of climate modification is the possibility of new perched water bodies forming either above or below the repository. The potential effect of perched water above the repository is the redirection of percolation flux for interaction with the repository. However, the current seepage abstraction contains a wide range of seepage due to encompass flow focusing and variability (CRWMS M&O 2000o; Section 6). Therefore, the effects of perched water are included indirectly in the seepage abstraction model. The effects of perched water below the repository are excluded on the basis of low consequence, as discussed in Section 6.2.1.

6.3.5 Flow and Transport in the UZ from Episodic Infiltration (2.2.07.05.00)

YMP Primary FEP Description: Episodic flow occurs in the UZ as a result of episodic infiltration. See also FEP 2.2.07.02.00 (unsaturated groundwater flow), 2.3.11.03.00 (infiltration), 2.2.07.04.00 (focusing of UZ flow), and 1.3.01.00.00 (climate change). Episodic flow may affect transport; for example, colloidal transport may be enhanced by episodic flow.

Disposition: Exclude effects of episodic flow resulting from episodic infiltration on the basis of low consequence. Include the effects of transient flow due to thermal-hydrologic processes on drift seepage. Exclude the effects of transient flow due to thermal-hydrologic processes on radionuclide transport on the basis of low consequence.

Screening Argument: The process that drives infiltration in the unsaturated zone is precipitation, which is clearly episodic in nature. Studies of episodic infiltration and percolation have found, however, that matrix-dominated flow in the PTn damps out the transient nature of the percolation such that unsaturated zone flow below the PTn is essentially steady (CRWMS

M&O 1998c, Section 2.4.2.8) Furthermore, the PTn is found over the entire repository block (see Attachment IX). This damping of transient flow is due to capillary forces and high matrix permeability in the PTn that lead to matrix imbibition of water from fractures the matrix. Therefore, this FEP is excluded on the basis that the unsaturated zone flow is steady at the repository and along radionuclide transport pathways. The effects of transient flow driven by thermo-hydrologic processes are included in TSPA calculations for drift seepage (CRWMS M&O 2000o; Section 6). The effects of such transient flow processes on mountain-scale flow and radionuclide transport is expected to be minimal (Assumption 13). Very small amounts of fracture flow do appear to penetrate as a transient through fault zones between the ground surface and the repository elevation as evidenced by high ^{36}Cl concentrations in samples taken from the ESF. Higher concentrations of this isotope found in the ESF can only be explained through surface deposition of ^{36}Cl from nuclear weapons testing and subsequent aqueous transport to certain ESF sampling locations in a period of approximately 50 years. However, the flow and transport models indicate that the quantity of water and dissolved constituents that do penetrate the PTn as a flow transient is negligible with respect to repository performance (CRWMS M&O 1998c, Section 2.4.2.8).

6.3.6 Episodic / Pulse Release from Repository (2.2.07.06.00)

YMP Primary FEP Description: Episodic release of radionuclides from the repository and radionuclide transport in the UZ may occur both because of episodic flow into the repository (see 2.2.07.05.00, episodic flow in UZ), and because of other factors including intermittent failures of waste packages.

Disposition: Exclude effects of episodic flow resulting from episodic infiltration on the basis of low consequence. Include the effects of transient flow due to thermal-hydrologic processes on drift seepage. Exclude the effects of transient flow due to thermal-hydrologic processes on radionuclide transport on the basis of low consequence. Include the effects of intermittent waste package failures.

Screening Argument: This FEP refers to the effects of episodic flow and intermittent waste package failures to produce pulse releases of radionuclides from the repository. The effects of episodic flow at the mountain scale are excluded on the basis of low consequence, as discussed in Section 6.3.5. The effects of transient flow driven by thermo-hydrologic processes are included in TSPA calculations for drift seepage (CRWMS M&O 2000o; Section 6). The effects of intermittent waste package failures are included in the source term model for TSPA (CRWMS M&O 2000t; Section 6).

6.3.7 Perched Water Develops (2.2.07.07.00)

YMP Primary FEP Description: Zones of perched water may develop above the water table. If these zones occur above the repository, they may affect UZ flow between the surface and the waste packages. If they develop below the repository, for example at the base of the Topopah Spring welded unit, they may affect flow pathways and radionuclide transport between the waste packages and the saturated zone.

Disposition: Exclude effects of perched water below repository on the basis of low consequence. Include the effects of increased flux through repository, water table rise and present-day perched water.

Screening Argument: The FEP refers to the possibility of new perched water bodies forming either above or below the repository under future climates. The potential effect of perched water above the repository is the redirection of percolation flux for interaction with the repository. However, the current seepage abstraction contains a wide range of seepage due to encompass flow focusing and variability (CRWMS M&O 2000o; Section 6). Therefore, the effects of perched water are included indirectly in the seepage abstraction model. The effects of existing perched water zones are included (CRWMS M&O 2000c; Section 6). The effects of changes to perched water below the repository are excluded on the basis of low consequence, as discussed in Section 6.2.1.

6.3.8 Infiltration and Recharge (Hydrologic and Chemical Effects) (2.3.11.03.00)

YMP Primary FEP Description: Infiltration into the subsurface provides a boundary condition for groundwater flow. The amount and location of the infiltration influences the hydraulic gradient and the height of the water table. Different sources of recharge water could change the chemistry of groundwaters passing through the repository. Mixing of these waters with other groundwaters could result in precipitation, dissolution and altered chemical gradients.

Disposition: Exclude effects of changes to water chemistry on the basis of low consequence. Include the effects of changing infiltration and water table rise.

Screening Argument: The hydrologic effects of infiltration and recharge are included in the infiltration model (CRWMS M&O 2000b; Section 6). This is incorporated into the TSPA through the unsaturated zone flow fields that use the infiltration model results as upper boundary conditions (CRWMS M&O 2000c; Section 6 and CRWMS M&O 2000w; Section 6). The effects of changes in infiltration water chemistry under different climates are assumed to be minimal (Assumption 10). Therefore, this aspect of the FEP is excluded from TSPA based on low consequence.

6.4 EROSION/DISSOLUTON/SUBSIDENCE

This group of FEPs are generally excluded from the TSPA calculation, although there are some exceptions as noted in the FEP screening arguments given below. These FEPs concern the effects of surface erosion, mineral dissolution, and subsidence on hydrologic conditions, flow, and radionuclide transport in the unsaturated zone. All of these processes are expected to occur at Yucca Mountain at low levels of activity. These FEPs are all excluded on the basis of low consequence given conservative bounds on the extent that these processes can affect the hydrogeologic system at Yucca Mountain in a 10,000-year period.

Table 6 gives the FEP numbers for the YMP primary FEPs, the primary FEP titles, and some, but not all, of the secondary FEP titles for this category. Not all the secondary FEP titles are listed because many are identical, or nearly identical to the primary FEP title or to other secondary FEP titles under the same primary FEP. A listing of the description of each of the primary and secondary FEPs in this category is given in Attachment IV.

Table 6. Excluded FEPs: Erosion/Dissolution/Subsidence

YMP Primary FEP Number	Primary FEP Title	Secondary FEPs Titles
1.2.07.01.00	Erosion/denudation	• Major incision • Generalized denudation • Localized denudation • Solid discharge via erosion process • Basement alteration • Hydraulic gradient changes (magnitude, direction) • Ephemeral stream erosion cuts Tiva Canyon units to underlying nonwelded units • Land slide • Chemical denudation and weathering • Fluvial erosion/sedimentation • Aeolian erosion • Mass wasting • Mechanical weathering
1.2.07.02.00	Deposition	• Aeolian deposition • Lacustrine deposition
1.2.09.02.00	Large-scale dissolution	• Shallow dissolution • Lateral dissolution • Solution chimneys • Breccia pipes • Collapse breccias
2.2.06.04.00	Effects of subsidence	• Large-scale rock fracturing • Borehole-induced solution and subsidence

6.4.1 Erosion/Denudation (1.2.07.01.00)

YMP Primary FEP Description: Erosion and denudation are processes which cause significant changes in the present-day topography and thus affect local and regional hydrology and the biosphere. Erosion of surficial materials can occur by a variety of means, including physical weathering (including glacial and fluvial erosion), chemical weathering, erosion by wind (aeolian erosion), and mass wasting (e.g., landslide) processes. The extent of erosion depends to a large extent on climate and uplift.

Disposition: Exclude on the basis of low consequence.

Screening Argument: Erosion is a process that is expected to be ongoing at Yucca Mountain over the 10,000-year performance period. The maximum erosion over a 10,000 year period is expected to be less than 10 cm (YMP 1993, p. 55), which is within the range of existing surface irregularities. Therefore, the effects of surface erosion are expected to be negligible (Assumption 4). The effects of radionuclides that may be present in surface soils or rock at the accessible environment, which subsequently enter the biosphere through erosion processes, are included (CRWMS M&O 2000u; Section 6).

6.4.2 Deposition (1.2.07.02.00)

YMP Primary FEP Description: Deposition and erosion are processes which cause significant changes in the present-day topography and thus affect local and regional hydrology and the biosphere. Deposition of surficial materials can occur by a variety of means, including fluvial, aeolian, and lacustrine deposition and redistribution of soil through weathering and mass wasting processes.

Disposition: Exclude on the basis of low consequence.

Screening Argument: Like erosion, deposition is a process that is expected to be ongoing at Yucca Mountain over the 10,000-year performance period. However, given the topographic character of Yucca Mountain, erosion is expected to dominate over deposition. Deposition is believed to be a dominant process in Fortymile Wash (YMP 1993, p. 55). However, this drainage channel has no effect on unsaturated zone flow and transport at Yucca Mountain due to its lateral offset. Therefore deposition is excluded from TSPA on the basis of low consequence.

6.4.3 Large-Scale Dissolution (1.2.09.02.00)

YMP Primary FEP Description: Dissolution can occur when any soluble mineral is removed by flowing water, and large-scale dissolution is a potentially important process in rocks that are composed predominantly of water-soluble evaporite minerals, such as salt.

Disposition: Exclude on the basis of low probability.

Screening Argument: This FEP is principally concerned with the dissolution of highly soluble evaporite rocks such as halite or carbonates. Evaporitic minerals are present, but the unsaturated zone at Yucca Mountain is primarily composed of vitric high-silica rhyolite and quartz latite (or trachyte) (CRWMS M&O 1998a; Section 3.5.2.1, paragraph 7). Solubilities of these minerals are too low to produce large dissolution cavities. Local dissolution processes that affect, for example, fracture filling minerals are discussed in Section 6.8.8.

6.4.4 Effects of Subsidence (2.2.06.04.00)

YMP Primary FEP Description: Subsidence above the mined underground facility or other openings affects the properties of the overlying rocks and surface topography. Changes in rock properties, such as enhanced permeability, may alter flow paths from the surface to the repository. Changes in surface topography may alter run-off and infiltration, and may perhaps create impoundments.

Disposition: Exclude on the basis of low consequence.

Screening Argument: Subsidence can occur as a result of underground excavations. In coal mining, subsidence has been found to occur when more than 50% of the coal bed was removed (Keller 1992; p. 142). In the case of Yucca Mountain, the percent of removal of is very small. The emplacement drift diameter is less than 10% of the drift spacing (CRWMS M&O 2000aa; Section 1.2.1). Furthermore, drift collapse has been modeled for drift seepage considerations (CRWMS M&O 2000d; Section 6) and the collapse is found to only extend about 9 meters above the initial drift crown elevation. The effects of changes to fracture characteristics around emplacement drifts due to stress relief and drift collapse is discussed in Section 6.8.3. Therefore, subsidence is expected to have a negligible impact on large-scale unsaturated zone flow or surface topography and is excluded from TSPA modeling.

6.5 HUMAN INFLUENCES ON CLIMATE/SOIL

This group of FEPs are excluded from the TSPA calculation. These FEPs concern the effects of human activity on regional and global climate, as well as local effects on soils. These FEPs are all excluded on the basis of conservative assumptions used in climate modeling and the ranges of parameters used to characterized unsaturated zone water chemistry.

Table 7 gives the FEP numbers for the YMP primary FEPs, the primary FEP titles, and some, but not all, of the secondary FEP titles for this category. Not all the secondary FEP titles are listed because many are identical, or nearly identical to the primary FEP title or to other secondary FEP titles under the same primary FEP. A listing of the description of each of the primary and secondary FEPs in this category is given in Attachment V.

Table 7. Excluded FEPs: Human Influences on Climate/Soil

YMP Primary FEP Number	Primary FEP Title	Secondary FEPs Titles
1.4.01.00.00	Human influences on climate	None
1.4.01.02.00	Greenhouse gas effects	None
1.4.01.03.00	Acid rain	• Surface water pH
1.4.01.04.00	Ozone layer failure	None
1.4.06.01.00	Altered soil or surface water chemistry	• Groundwater pollution • Surface pollution (soils, rivers) • Altered soil or surface water chemistry by human activities • Far-field hydrochemistry – acids, oxidants, nitrate • Arable farming

6.5.1 Human Influences on Climate (1.4.01.00.00)

YMP Primary FEP Description: This category contains FEPs related to future human actions that could influence global, regional, or local climate. Human actions may be intentional or accidental. This FEP aggregates all human influences on climate into a single category. Technical discussions are presented separately for increased recharge (1.4.01.01.00), greenhouse gas effects (1.4.01.02.00), acid rain (1.4.01.03.00), and ozone layer failure (1.4.01.04.00).

Disposition: Exclude on the basis of low consequence.

Screening Argument: Human activities are suspected of having some effects on climate. In particular, global warming due to emission of greenhouse gases is one example of the potential consequences of human activity on global climate. However, human activities are not the only factor important to climate change. Major changes in climate are known to have occurred prior to any significant human activities (USGS 2000a; Section 6). By incorporating changes to wetter climates driven by glacial cycles during the 10,000-year performance period, the potential effects of human activities on climate are conservatively bounded (Assumption 5). Therefore, the effects of human activity on climate are excluded from TSPA.

6.5.2 Greenhouse Gas Effects (1.4.01.02.00)

YMP Primary FEP Description: The greenhouse effect refers to the presence of carbon dioxide and other gases in the atmosphere that tend to allow solar radiation through to the earth's surface and reflect heat back to it. Thus, these gases act much as the glass of a greenhouse, with the earth as the greenhouse. Human activities such as burning of fossil fuels, forest clearance, and industrial processes produce these greenhouse gases. The greenhouse effect could increase concentrations of carbon dioxide and other gases in the atmosphere, and lead to changes in climate such as global warming.

Disposition: Exclude on the basis of low consequence.

Screening Argument: This FEP is closely related to the one discussed in Section 6.5.1. Human activities are suspected of having some effects on climate. In particular, global warming due to emission of greenhouse gases is one example of the potential consequences of human activity on global climate. However, human activities are not the only factor important to climate change. Major changes in climate are known to have occurred prior to any significant human activities (USGS 2000a; Section 6). By incorporating changes to wetter climates driven by glacial cycles during the 10,000-year performance period, the potential effects of human activities on climate are conservatively bounded (Assumption 5). Therefore, the effects of human activity on climate are excluded from TSPA.

6.5.3 Acid Rain (1.4.01.03.00)

YMP Primary FEP Description: Human actions may result in acid rain on a local to regional scale. Acid rain can detrimentally affect aquatic and terrestrial life by interfering with the growth, reproduction and survival of organisms. It can influence the behavior and transport of contaminants in the biosphere, particularly by affecting surface water and soil chemistry.

Disposition: Exclude on the basis of low consequence.

Screening Argument: Acid rain is found to occur as a result of human activities, particularly combustion products containing sulfur and nitrogen oxides (Keller 1992; p. 432). However, Yucca Mountain lies in an area of relatively high calcic soils common to desert environments (Taylor 1986, p. 34). The carbonate content of soils and rock tend to buffer the effects of acidic rainwater (Keller 1992; pp. 432, 433). Furthermore, there are numerous other factors that are expected to have more effect on water chemistry than acid rain, including the thermal and materials interactions of the repository (see Sections 6.8.6, 6.8.7, 6.8.8, 6.8.16, 6.8.17, 6.8.18). Therefore, the effects of acid rain are excluded from TSPA.

6.5.4 Ozone Layer Failure (1.4.01.04.00)

YMP Primary FEP Description: Human actions (i.e., the use of certain industrial chemicals) may lead to destruction or damage to the earth's ozone layer. This may lead to significant changes to the climate, affecting properties of the geosphere such as groundwater flow patterns.

Disposition: Exclude on the basis of low consequence.

Screening Argument: This FEP is closely related to the one discussed in Section 6.5.1. Human activities are suspected of having some effects on climate. In particular, global warming due to emission of greenhouse gases is one example of the potential consequences of human activity on global climate. However, human activities are not the only factor important to climate change. Major changes in climate are known to have occurred prior to any significant human activities (USGS 2000a; Section 6). By incorporating changes to wetter climates driven by glacial cycles during the 10,000-year performance period, the potential effects of human activities on climate are conservatively bounded (Assumption 5). Therefore, the effects of human activity on climate are excluded from TSPA.

6.5.5 Altered Soil or Surface Water Chemistry (1.4.06.01.00)

YMP Primary FEP Description: Human activities (e.g., industrial pollution, agricultural chemicals) may produce local changes to the soil chemistry or to the chemistry of water infiltrating Yucca Mtn and could provide a plume of unspecified nature to interact with the repository and possibly with containers.

Disposition: Exclude on the basis of low probability.

Screening Argument: Human activities may affect soil and surface water chemistry due to agricultural activities or pollution from industrial activities. Current land use at Yucca Mountain does not include activities such as these that may lead to large-scale changes in soil or water chemistry and there is no basis to predict that such activity will occur in the future. Therefore, the effects of human activities on soil and water chemistry are excluded from TSPA.

6.6 NATURAL GAS/GAS GENERATION EFFECTS

This group of FEPs are excluded from the TSPA calculation. These FEPs concern the effects of gas generation due to chemical reactions in the repository, the intrusion of naturally occurring gases such as methane, and gas-phase radionuclide transport. These FEPs are all excluded on the basis of low consequence to performance.

Table 8 gives the FEP numbers for the YMP primary FEPs, the primary FEP titles, and some, but not all, of the secondary FEP titles for this category. Not all the secondary FEP titles are listed because many are identical, or nearly identical to the primary FEP title or to other secondary FEP titles under the same primary FEP. A listing of the description of each of the primary and secondary FEPs in this category is given in Attachment VI.

Table 8. Excluded FEPs: Natural Gas/Gas Generation Effects

YMP Primary FEP Number	Primary FEP Title	Secondary FEPs Titles
2.1.12.01.00	Gas generation	• Formation of gases (in waste and engineered barrier system) • Gas generation, buffer/backfill • Chemotoxic gasses (in waste and engineered barrier system) • Pressurization (in waste and engineered barrier system)
2.2.10.11.00	Natural air flow in unsaturated zone	None
2.2.11.01.00	Naturally-occurring gases in geosphere	• Methane intrusion • Geogas • Gas generation and gas sources, far-field
2.2.11.02.00	Gas pressure effects	• Fluid flow due to gas pressurization (in waste and engineered barrier system)
2.2.11.03.00	Gas transport in geosphere	• Gases and gas transport • Far-field transport: gas induced groundwater transport • Gas-mediated transport • Far-field transport: transport of radioactive gases • Gas discharge

6.6.1 Gas Generation (2.1.12.01.00)

YMP Primary FEP Description: Gas may be generated in the repository by a variety of mechanisms. Gas generation might lead to pressurization of the repository, produce multiphase flow, and affect radionuclide transport. This FEP aggregates all types of gas generation into a single category. Technical discussions are presented separately for gas generation from fuel decay (FEP 2.1.12.02.00), corrosion (FEP 2.1.12.03.00), microbial degradation (FEP 2.1.12.04.00), and radiolysis (FEP 2.1.13.01.00).

Disposition: Exclude on the basis of low consequence.

Screening Argument: This FEP refers to the generation of gases in the repository as a result of thermal-chemical and radiolysis reactions. Some of the consequences include the production of corrosive or explosive gases such as hydrogen sulfide. The physical/chemical effects of gas generation, primarily the interplay of O_2, CO_2, and H_2O (vapor), are addressed in CRWMS M&O (2000r; Section 6 and 2000y; Section 6). No corrosive or explosive gases have been identified (CRWMS M&O 2000y; Section 6). In the unsaturated zone of Yucca Mountain, the build-up of any significant gas pressure is unlikely due to the permeable fracture pathways (Assumption 6). Therefore, this aspect of the effect of gas generation is excluded from TSPA.

6.6.2 Natural Air Flow in Unsaturated Zone (2.2.10.11.00)

YMP Primary FEP Description: Natural convective air circulation has been observed at a borehole at the top of the mountain. Repository heat is expected to increase this flow.

Disposition: Exclude on the basis of low consequence.

Screening Argument: Natural air flow is expected to have a negligible impact on thermo-hydrologic processes due to the large volume of thermally-generated water-vapor flow. With respect to radionuclide transport, no radionuclides are transported in the gas phase; all radionuclides move in the aqueous phase. The effects of natural air flow have little consequence on water movement in the unsaturated zone because of the high mobility of the gas phase, hence little dynamic interaction between the phases. A standard approximation for unsaturated flow is to neglect the effects of the gas phase.

6.6.3 Naturally-Occurring Gases in Geosphere (2.2.11.01.00)

YMP Primary FEP Description: Naturally-occurring gases in the geosphere may intrude into the repository or may influence groundwater flow paths and releases to the biosphere. Potential sources for gas might be clathrates, microbial degradation of organic material or deep gases in general.

Disposition: Exclude on the basis of low consequence and low probability.

Screening Argument: This FEP refers to the possible occurrence of gases such as methane that could enter the repository or affect radionuclide pathways. However, no methane or other "geogases" have been detected in the site characterization activities at Yucca Mountain. Carbon dioxide is at elevated levels in the unsaturated zone compared with the atmosphere but this is believed to be generated in the soil horizon. Furthermore, with the repository in the unsaturated zone in a highly fractured rock, there is no mechanism for build-up of intrusive gases (Assumption 6). Therefore, this FEP is excluded from TSPA.

6.6.4 Gas Pressure Effects (2.2.11.02.00)

YMP Primary FEP Description: Pressure variations due to gas generation may affect flow patterns and contaminant transport in the geosphere.

Disposition: Exclude on the basis of low consequence and low probability.

Screening Argument: This FEP is very similar in nature to those discussed in Sections 6.6.1 and 6.6.3. In the unsaturated zone of Yucca Mountain, the build-up of any significant gas pressure is unlikely due to the permeable fracture pathways (Assumption 6). Therefore, this aspect of the effect of gas generation is excluded from TSPA.

6.6.5 Gas Transport in Geosphere (2.2.11.03.00)

YMP Primary FEP Description: Gas released from the drifts and gas generated in the near-field rock will flow through fracture systems in the near-field rock and in the geosphere. Certain gaseous or volatile radionuclides may be able to migrate through the far-field faster than the groundwater advection rate. Degassing could affect flow and transport of gaseous contaminants. Gases could also affect other contaminants if water flow is driven by large gas bubbles forming in the repository.

Disposition: Exclude on the basis of low consequence and low probability.

Screening Argument: This FEP refers to the release of gas-phase radionuclides through gas bubbles. Because the repository at Yucca Mountain would be located in the unsaturated zone, releases to the gas phase would be direct. Therefore, the bubble-release mechanism is not relevant and this FEP is excluded from TSPA. Releases of volatile radionuclides are excluded on the basis that all radionuclides in TSPA are released into the aqueous phase. This is expected to bound any dose effects of gas-phase releases due to the large dilution of gas-phase releases in the atmosphere.

6.7 SEISMIC/IGNEOUS/ROCK CHARACTERISTICS

This group of FEPs constitutes a mixture of items both included and excluded from the TSPA calculation. These FEPs concern the effects of rock characteristics, and geologic processes that can affect rock characteristics, such as seismic and igneous processes. Although all existing characteristics are included in TSPA, some of the processes that may influence these characteristics are excluded on the basis of low consequence. Other effects believed to be more important are included.

Table 9 gives the FEP numbers for the YMP primary FEPs, the primary FEP titles, and some, but not all, of the secondary FEP titles for this category. Not all the secondary FEP titles are listed because many are identical, or nearly identical to the primary FEP title or to other secondary FEP titles under the same primary FEP. A listing of the description of each of the primary and secondary FEPs in this category is given in Attachment VII.

Table 9. Included/Excluded FEPs: Seismic/Igneous/Rock Characteristics

YMP Primary FEP Number	Primary FEP Title	Secondary FEPs Titles
1.2.02.01.00	Fractures	• Changes in fracture properties • Fracturing
1.2.02.02.00	Faulting	• Fault generation • Fault activation • Movements along small-scale faults • Formation of new faults • Fault movement • Normal faulting occurs or exists at Yucca Mountain • Strike-slip faulting occurs or exists at Yucca Mountain • Detachment faulting occurs or exists at Yucca Mountain • Dip-slip faulting occurs at Yucca Mountain
		• Old fault strand is reactivated at Yucca Mountain • New fault strand is reactivated at Yucca Mountain • Movements along major faults
1.2.03.01.00	Seismic activity	• Earthquakes • Seismicity • Seismic activity

Table 9. Included/Excluded FEPs: Seismic/Igneous/Rock Characteristics (continued)

YMP Primary FEP Number	Primary FEP Title	Secondary FEPs Titles
1.2.04.02.00	Igneous activity causes changes to rock properties	• Dike provides a permeable flow path • Dike provides a barrier to flow • Volcanic activity in the vicinity produces an impoundment • Igneous activity causes extreme changes to rock geochemical properties • Intrusion (magmatic) • Dike related fractures after flow • Magmatic activity
1.2.06.00.00	Hydrothermal activity	None
1.2.10.01.00	Hydrological response to seismic activity	• Fault movement pumps fluid from SZ to UZ (seismic pumping) • Fault creep causes short term fluctuations of the water table • New faulting breaches flow barrier controlling large hydraulic gradient to the north • Normal faulting produces a trap for laterally moving moisture in the Tiva Canyon unit • Head-driven flow up from carbonates • Fault pathway through the altered Topopah Spring basal vitrophyre
		• Fault movement connects tuff and carbonate aquifers • Fault establishes pathway through the UZ • Fluid supplied by a fault migrates down the drift • Fault intersects and drains condensate zone • Flow barrier south of site blocks flow, causing water table to rise
1.2.10.02.00	Hydrologic response to igneous activity	• Interaction of water table with magma • Interaction of unsaturated zone pore water with magma

Table 9. Included/Excluded FEPs: Seismic/Igneous/Rock Characteristics (continued)

YMP Primary FEP Number	Primary FEP Title	Secondary FEPs Titles
2.2.06.02.00	Changes in stress (due to thermal, seismic, or tectonic effects) produce change in permeability of faults	• Aseismic alteration of permeability along and across faults • Fracture dilation along faults creates zones of enhances permeability • Relaxation of thermal stresses by fault movement • Seismically-stimulated release of thermo-mechanical stress on bounding faults
2.2.06.03.00	Changes in stress (due to seismic or tectonic effects) alter perched water zones	• Perched zones develop as a result of stress changes
2.2.12.00.00	Undetected features (in geosphere)	• Undetected dike beneath the repository passing through the Calico Hills provides a highly permeable flow path • Undetected fault dips below the repository providing a highly permeable flow path • Undetected fault beneath the repository acts as a flow barrier altering the flow system • Perched water escapes detection and waste is put in it • Undiscovered mine shaft (an old prospect hole) in a wash acts as a source for increased local infiltration • Undetected fracture zone • Undetected past intrusions • Undetected discontinuities

6.7.1 Fractures (1.2.02.01.00)

YMP Primary FEP Description: Groundwater flow in the Yucca Mountain region and transport of any released radionuclides may take place along fractures. Transmissive fractures may be existing, reactivated, or newly formed fractures. The rate of flow and the extent of transport in fractures is influenced by characteristics such as orientation, aperture, asperity, fracture length, connectivity, and the nature of any linings or infills. Generation of new fractures and reactivation of preexisting fractures may significantly change the flow and transport paths. Newly formed and reactivated fractures typically result from thermal, seismic, or tectonic events.

Disposition: Include effects of present-day fracture system. Exclude the effects of changes to the fracture system on the basis of low consequence.

Screening Argument: This FEP concerns a characteristic feature of Yucca Mountain geology. The present-day fracture system is directly included in the flow and transport models of the unsaturated zone (CRWMS M&O 2000l; Section 6). The effects of changes to the fracture system due to geologic or geochemical effects on mountain-scale flow and radionuclide transport have been investigated using a sensitivity approach (CRWMS M&O 2000e; Section 6). The results indicate that radionuclide transport results are relatively insensitive to large variations in the fracture aperture.

Fault displacements may change the mechanical stress in the vicinity of emplacement drifts, resulting in changes to fracture aperture. The effects of changes to the mechanical stress due to faults are expected to be small in comparison with the mechanical stresses due to the presence of the drift (Assumption 15). Therefore, changes to the fracture characteristics in the vicinity of waste emplacement drifts are excluded from TSPA on the basis of low consequence.

6.7.2 Faulting (1.2.02.02.00)

YMP Primary FEP Description: Faulting may occur due to sudden major changes in the stress situation (e.g. seismic activity) or due to slow motions in the rock mass (e.g., tectonic activity). Movement along existing fractures and faults is more likely than the formation of new faults. Faulting may alter the rock permeability in the rock mass and alter or short-circuit the flow paths and flow distributions close to the repository and create new pathways through the repository. New faults or the cavitation of existing faults may enhance the groundwater flow, thus decreasing the transport times for potentially released radionuclides.

Disposition: Include effects of present-day faults. Exclude the effects of changes to the faults on the basis of low consequence.

Screening Argument: Like fractures, faulting is a characteristic feature of Yucca Mountain geology. The present-day faults are directly included in the flow and transport models of the unsaturated zone (CRWMS M&O 2000l; Section 6). Fault movements can affect the fracture properties through changes in rock stress. This aspect of the problem is discussed in Section 6.7.1. Fault movements can also change the properties of the faults themselves, and this aspect has been investigated with a sensitivity study (CRWMS M&O 2000e; Section 6). This study found that radionuclide transport in the unsaturated zone is very insensitive to the fault properties. Because waste emplacement drifts are not located in fault zones, there are no effects of changes in fault properties on drift seepage. Thus we exclude the effects of changes in fault properties in TSPA.

Another aspect of faulting that could be important is the formation of new faults, particularly within the repository block. However, CRWMS M&O (1998b; Figure 8-8, 8-9, and 8-10) indicates that the probability of new fault movements along small faults (with 2 meter displacement) have a annual exceedance probability for movement of more than 1 m to be less than 10^{-4} in 10,000 years. Therefore small faults will remain small. The magnitude of potential future displacements along faults with smaller present-day displacements or along fractures are likewise smaller. Therefore, the effects of new faults are expected to be negligible and are excluded from TSPA.

6.7.3 Seismic Activity (1.2.03.01.00)

YMP Primary FEP Description: Seismic activity (i.e., earthquakes) could produce jointed-rock motion, rapid fault growth, slow fault growth or new fault formation, resulting in changes in hydraulic heads, changes in groundwater recharge or discharge zones, changes in rock stresses, and severe disruption of the integrity of the drifts (e.g., vibration damage, rockfall).

Disposition: Exclude on the basis of low consequence.

Screening Argument: The relevant aspects of this FEP with respect to the unsaturated zone have been discussed in Sections 6.7.1 and 6.7.2. The effects of seismic activity on fractures are found to have low consequence for both mountain-scale radionuclide transport and for seepage into waste emplacement drifts. Changes to fault properties are found to have low consequence on performance issues concerning radionuclide transport and drift seepage. Finally, the formation of new faults or enhancement of small faults into major faults are found to have an annual exceedance probability of less than 10^{-8}. Therefore, the effects of changes to the fracture system and faults have been excluded in the TSPA on the basis of low consequence and low probability.

6.7.4 Igneous Activity Causes Changes to Rock Properties (1.2.04.02.00)

YMP Primary FEP Description: Igneous activity near the underground facility causes extreme changes to rock hydrologic and mineralogic properties. Permeabilities of dikes and sills and the heated regions immediately around them can differ from those of country rock. Mineral alterations can also change the chemical response to contaminants.

Disposition: Exclude on the basis of low consequence.

Screening Argument: Basaltic igneous activity typically has minimal physical and mineralogical effects on local rock properties. Basalt magma chills rapidly against country rock, forming a non-vesicular apahanitic border facies having low thermal conductivity and low chemical reactivity. The country rock itself may be baked to form a thin rind or hornfels. It is unlikely that contact mineral alterations would change the chemical response to contaminants, as alteration usually results in only a dense screen of aphanitic anhydrous silicate minerals. Any such alteration in the welded tuff units would be minimal owing to the dearth of hydrous minerals and the large component of high-temperature feldspars in the tuff. However, basalt contact with nonwelded units rich in zeolites might produce a significant zone of alteration. In this case, a barrier to groundwater flow might be appreciable in a rock that has relatively high pore permeability. Unlike siliceous alteration associated with granitic magma, thermal alteration associated with basalts is narrowly confined and of short duration. An insignificant amount of volatiles enters the host rock from the cooling basalt dike. A dike intersecting the saturated zone will freeze against the bedrock. At this point the magma is degassing and crystallizing - it will not absorb groundwater nor form a local hydrothermal cell. Therefore, the thermal and chemical effects would be very local and transient, lasting at most for several days to several months, and not extending for more than a meter or two from the dike margin. On the basis of these confined and short duration features and processes, this FEP is excluded on basis of low consequence.

6.7.5 Hydrothermal Activity (1.2.06.00.00)

YMP Primary FEP Description: This category contains FEPs associated with naturally-occurring high-temperature groundwaters, including processes such as density-driven groundwater flow and hydrothermal alteration of minerals in the rocks through which the high temperature groundwater flows.

Disposition: Exclude on the basis of low probability.

Screening Argument: Hydrothermal activity refers to the alteration or precipitation of minerals in the presence of hot water, generally below 400°C. Hydrothermal activity is usually characterized by replacement assemblages or vein deposits of silica and calcite and clay minerals, and by sulfides such as pyrite. Hydrothermal activity usually represents the last cooling stage of magmatic intrusion when residual water is passed from the crystallizing melt, and/or its heat flux is sufficient to set up local deep groundwater convection such that hot, mineral laden solutions pass upwards to cool and precipitate in a halo around the intrusion; the country rock literally stews in hot fluid for periods of hundreds to thousands of years. Hydrothermal mineralization is not to be confused with deuteric alteration, which has affected the tuffs at Yucca Mountain. In this case, as the tuffs cooled and devolatized, aqueous or gaseous components exsolved from the tuff and precipitated calcite, opal, or zeolites, especially in lithophysae and less commonly in small, discontinuous veins. Many of these late minerals have fluid inclusions that indicate elevated temperatures, or hydrothermal conditions, but they do not indicate operation of a hydrothermal system of alteration.

Hydrothermal activity is conspicuous in the Calico Hills and along the south flank of Shoshone Mountain, but comparable hydrothermal activity has not been identified at Yucca Mountain. The Calico Hills is an intrusion-related dome, but Yucca Mountain is located outside the caldera margin, hence it was never near a hydrothermal source (CRWMS M&O 1998a, Figure 3.5-2). Unless it could be demonstrated that major silicic magmatism is imminent near Yucca Mountain, there is no possibility for future hydrothermal activity at or near the mountain (Assumption 7). Therefore, the effects of hydrothermal activity are excluded from TSPA on the basis of low probability.

6.7.6 Hydrological Response To Seismic Activity (1.2.10.01.00)

YMP Primary FEP Description: Seismic activity, associated with fault movement, may create new or enhanced flow pathways and/or connections between stratigraphic units, or it may change the stress (and therefore fluid pressure) within the rock. These responses have the potential to significantly change the surface- and groundwater flow directions, water level, water chemistry and temperature.

Disposition: Exclude on the basis of low consequence and low probability.

Screening Argument: This FEP includes the effects of seismic activity on unsaturated zone flow and transport at the mountain scale and for drift seepage. It also includes the possible water table rise in response to seismic activity. The aspects of this FEP related to flow and transport are addressed in Sections 6.7.1, 6.7.2, and 6.7.3. Here we assess the effects of seismically induced water table rise.

Seismic pumping (Szymanski, 1989; p 3-22) is the temporary increase in height of the water table caused by fault movement. This movement of the water table is caused by the opening and closing of fractures during an earthquake cycle. The observed similarity that exists among the hydrologic signatures both close to and far from the seismic slip suggests that the population of fractures are not significantly affected by proximity to the active fault (Muir-Wood and King, 1993; p. 22061). Longer term changes are due to complex strain adjustments, but these changes are dissipated under the influence of regional stress field, which brings the state of the SZ fracture network back to an ambient, pre-seismic state as postseismic relaxation occurs. Numerical simulations by Carrigan et al. (1991) of tectonohydrologic coupling involving earthquakes typical of the Basin and Range province (~ 1 m slip) produced 2 to 3 m excursions of a water table 500 m below ground surface. Extrapolation to an event of about 4 m slip would result in a transient rise of 17 m near the fault (Carrigan et al. 1991; p. 1159). Changes in water table along faults is a different story, as permeability along the fault plane is drastically altered by seismic slip (Bruhn, 1994). This phenomenon results in seismic pumping. Carrigan et al. (1991) modeled a 100-m wide fracture zone centered on a vertical fault, such that vertical permeability was increased 10^3. Water level excursions in the fracture zone was twice the amplitude as that in the adjacent block. For a fault-fracture zone with 1 m slip, transient excursions of about 12 m can occur.

Data and modeling results indicate that changes in water table elevation at Yucca Mountain are not likely to exceed several meters and are likely to be transient. Furthermore, distant earthquakes can cause high amplitude excursions. Fault slip at block bounding faults at Yucca Mountain could result in higher water table excursions along the faults because of seismic pumping. The very complex structure of the Paleozoic aquifer beneath Yucca Mountain makes any generalization of water table behavior impossible; local rise is as likely as local fall. What seems most reasonable is that the water table excursions due to earthquakes are very unlikely to threaten, even temporarily, the repository horizon. Therefore, the seismic effects on water table rise due to seismic pumping are excluded from TSPA on the basis of low consequence.

Another aspect of the water-table rise issue concerns the large hydraulic gradient. A large hydraulic gradient in the water table currently exists north of the potential repository. The water table quickly drops across this large hydraulic gradient by about 250 m. If this gradient could migrate southward, the resulting water table below the potential repository could be much higher than present-day conditions. For example, the work of Davies and Archambeau (1997; p.28) suggests that the gradient is a result of stress variations in the rock that are residual stress effects induced by the Timber Mountain caldera. Furthermore, they suggest that moderate earthquakes in this area could induce a sufficient change in geomechanical strain downstream of the current large hydraulic gradient to induce a similar gradient downstream of the potential repository, resulting in a large (150 m to 250 m) rise in the water table beneath the potential repository. However, the hypothesis regarding the residual stress effects of the 10 million-year (Ma) Timber Mountain caldera contradicts extensive previous experience in the region of the Nevada Test Site (Stock et al. 1985). This composite experience is compiled from 14 sources reporting results from diverse methods including hydraulic fracturing, overcoring stress measurements, earthquake focal mechanisms, borehole breakouts, orientations of explosion-produced fractures, and study of Quaternary faults and cinder-cone alignments. These studies show a reasonably uniform direction of extension between NW and W, with a mixed potential-slip regime of normal faulting (mainly for shallow indicators) and strike-slip faulting (mainly for deep indicators). The Davies and Archambeau discussion is also inconsistent with actual stress measurements in G-2 as reported by Stock and Healy (1988), which is cited, though erroneously, as a source of "slug-test" data. Stock and Healy (1988) characterize G-2 as being within the same ("combined normal and strike-slip") faulting regime as that indicated by the results from the three holes that they tested south of the large gradient. In fact, based on the stress measurements in the four holes, the tendency for strike-slip faulting is greatest in the southeastern hole, UE-25p#1, not in the northern Yucca Mountain area where G-2 is located as Davies and Archambeau propose. The actual data do not support a residual stress effect from the Timber Mountain caldera, do not support a modern stress field changing from strike-slip in northern Yucca Mountain to normal south of the hydraulic gradient, and do not support a southward decrease of the least principal stress. Although it is reasonable that the area of the large hydraulic gradient is less transmissive than the area to the south-southeast, a more reasonable explanation for this lower transmissivity is that durable differences of lithology, alteration history, and structural deformation have affected this region, rather than a transient state of stress (Assumption 8). Therefore, the seismic effects on water table rise due to migration of the large hydraulic gradient are excluded from TSPA on the basis of low probability.

6.7.7 Hydrologic Response to Igneous Activity (1.2.10.02.00)

YMP Primary FEP Description: Igneous activity may change the groundwater flow directions, water level, water chemistry and temperature. Igneous activity includes magmatic intrusions which may change rock properties and flow pathways, and thermal effects which may heat up groundwater and rock.

Disposition: Exclude on the basis of low consequence.

Screening Argument: If lava were to dam one or more washes that drain the repository block the dam would probably not produce a large surface-water impoundment. Given the abundant unconsolidated channel and bank sediment and extensive colluvium in or near washes at Yucca Mountain, it is more likely that streams would grade by means of alluvial deposition to the lava dam spillway within a few decades. Such lava dams would probably not be effective in any case, as the lava would consist of clinker or aa (aa is a lava flow with a surface typified by angular, jagged blocks). Another potential effect (for which no data exist) would be the deposition of an ash cover on the repository block. This could increase infiltration since overland flow and sheet wash for all but the largest rainfall events might be appreciably inhibited by the highly porous ash or cinder blanket. However, unconsolidated ash a few centimeters thick likely would not last for more than a century.

Intrusion of a basalt dike at or near the repository block could present a radical contrast in hydrologic properties to the native rock, as it is likely that the basalt would have few, if any, fractures comparable to those of the tuff, and essentially no pore permeability. The net effect of dike intrusion would seem to be a rise in up-gradient water table but the effect should be strongly dependent on dike attitude and lateral continuity of a dike or dike swarm. Thus, even a relatively thin (several cm thick) subvertical dike oriented normal to the local flow gradient could, over time, create a groundwater dam. An important feature of some dike intrusions is collateral fracturing due to minor shear. This is significant because it can create pathways adjacent to the dike, augmenting hydrologic damming on the up-gradient side and perhaps draining perched water adjacent to a dike. The effects of perched water drainage are discussed in Section 6.7.9, with the conclusion that drainage of perched water is expected to have low consequence. Exposure of the 3.7 Ma basalt dikes in Crater Flat show an earlier sheared and fractured dike that has been cross cut at an acute angle by a later, less fractured dike. Generations of dikes affected by local deformation events that attend successive intrusive events could produce complex intersections of variably fractured dikes that both dam and afford complex pathways to groundwater flow. The mechanisms and the geometries are difficult to envision but could have some effects during times of high infiltration. Most likely, a proximal volcanic center would be located west or south of the repository block. Therefore, lava flows are not likely to ride up on the block. Any effects of such blockage on water table elevation are expected to have low consequence. Therefore this FEP is excluded on basis of low consequence.

6.7.8 Changes in Stress (Due to Thermal, Seismic, or Tectonic Effects) Produce Change in Permeability of Faults (2.2.06.02.00)

YMP Primary FEP Description: Stress changes due to thermal, tectonic and seismic processes result in strains that alter the permeability along and across faults.

Disposition: Exclude on the basis of low consequence.

Screening Argument: This FEP is similar in content to the one discussed in Section 6.7.2. Like fractures, faulting is a characteristic feature of Yucca Mountain geology. The present-day faults are directly included in the flow and transport models of the unsaturated zone (CRWMS M&O 2000l; Section 6). Fault movements can affect the fracture properties through changes in rock stress. This aspect of the problem is discussed in Section 6.7.1. Fault movements can also change the properties of the faults themselves, and this aspect has been investigated with a sensitivity study (CRWMS M&O 2000e; Section 6). This study found that radionuclide transport in the unsaturated zone is very insensitive to the fault properties. Because waste emplacement drifts are not located in fault zones, there are no effects of changes in fault properties on drift seepage. Thus we exclude the effects of changes in fault properties in TSPA.

6.7.9 Changes in Stress (Due to Seismic or Tectonic Effects) Alter Perched Water Zones (2.2.06.03.00)

YMP Primary FEP Description: Strain caused by stress changes from tectonic or seismic events alters the rock permeabilities that allow formation and persistence of perched water zones.

Disposition: Exclude effects of perched water changes below the potential repository on the basis of low consequence. Include effects of perched water changes above potential repository on drift seepage.

Screening Argument: No perched water has been found in site characterization boreholes or through other observations in the footprint of the potential repository at elevations higher than potential waste emplacement. However, the generation of perched water above the potential repository as a result of seismic activity could potentially affect the flow of water to waste emplacement drifts. This potential effect is indirectly included using a model for flow focusing in the seepage model abstraction, as discussed in CRWMS M&O (1990o).

Perched water zones below the elevation of the potential repository have been found in site characterization boreholes. The potential to release perched water as a result of stress changes and fracture openings driven by seismic activity should be considered. In that regard, the major bounding scenario identified for TSPA is the sudden release of perched water, along with its mobile radionuclides (Assumption 9). Although this may only have a small effect on the ultimate cumulative releases of radionuclides to the saturated zone, it could focus the radionuclide releases in a relatively sharp "pulse" when the perched water is allowed to drain. This possibility has been investigated by considering the volume of perched water in the fracture domain below the potential repository. The perched water in the fracture domain is the relevant feature because it is this volume that could potentially be quickly released to the saturated zone. Perched water in the matrix domain would also ultimately drain to the saturated zone, but this would be much slower and unlikely to cause any temporal pulses of radionuclide flux at the water table. The unsaturated zone flow model shows that the volume of perched water in the fracture domain below the potential repository ranges from about 3800 m^3 to 514,000 m^3. This volume may be compared with the water flux entering the potential repository footprint (i.e. that average infiltration rate times the area of the repository footprint), which ranges from 1300 m^3/yr to 191,000 m^3/yr. As shown in Attachment X, the perched water volume is seen to represent about from 0.4 to 55 years of water flux. This relatively small amount of water, and the radionuclides that could be contained in this water, is not expected to cause a significant "pulse" in radionuclide mass flux at the water table. Therefore, the effects of changes in perched water due to seismic effects are excluded from TSPA on the basis of either low probability (formation of new perched water) or low consequence (drainage of existing perched water).

6.7.10 Undetected Features (in Geosphere) (2.2.12.00.00)

YMP Primary FEP Description: This category contains FEPs related to undetected features in the geosphere that can affect long-term performance of the disposal system. Undetected but important features may be present, and have significant impacts. These features include unknown active fracture zones, inhomogeneities, faults and features connecting different zones of rock, different geometries for fracture zones and induced fractures due to the construction or presence of the repository.

Disposition: Exclude on the basis of low consequence and low probability.

Screening Argument: Two kinds of undetected features are of concern: (1) features which, on the basis of previous investigations, could be thought to be present, (2) features totally unexpected. Features that could be present include buried Plio-Pleistocene basaltic intrusions; these would be of such small dimension that detection by geophysical means would be difficult. As discussed in the Probabilistic Volcanic Hazard Analysis (PVHA) (CRWMS M&O 1996; Section 3), the presence of buried basalt dikes or plugs would shorten the recurrence interval of basaltic eruption and perhaps widen the spatial distribution of events, hence increasing the volcanic hazard at Yucca Mountain. Another undetected feature of considerable significance is the controlling structure of the large hydraulic gradient across the northern part of Yucca Mountain, a 300-m decline in potentiometric surface across a 2 km-width north of the potential repository. If the controlling feature is a fault zone rather than a facies change, tectonic reactivation could alter deep hydrologic flux in the vicinity of the repository.

It is very unlikely that a major, critical feature in the vicinity of Yucca Mountain, such as a large seismogenic fault zone, has been overlooked during site characterization. Such tectonic features, including buried strike-slip fault zones or shallow detachment faults, have been considered and factored into tectonic models evaluated by the PSHA , (CRWMS M&O 1998b). Therefore, the effects of undetected features are excluded on basis of low consequence. Any undetected features relevant to repository performance have been considered in uncertainty and hazard estimates in PVHA (CRWMS M&O 1996) and PSHA (CRWMS M&O 1998b).

6.8 REPOSITORY PERTURBED THMC

This group of FEPs constitutes a mixture of items both included and excluded from the TSPA calculation. These FEPs concern the effects of repository perturbations to the thermal/hydrologic/mechanical/chemical environment and the effects of these perturbations on hydrologic and geochemical processes that may be important to repository performance.

Table 10 gives the FEP numbers for the YMP primary FEPs, the primary FEP titles, and some, but not all, of the secondary FEP titles for this category. Not all the secondary FEP titles are listed because many are identical, or nearly identical to the primary FEP title or to other secondary FEP titles under the same primary FEP. A listing of the description of each of the primary and secondary FEPs in this category is given in Attachment VIII.

Table 10. Included/Excluded FEPs: Repository Perturbed THMC

YMP Primary FEP Number	Primary FEP Title	Secondary FEPs Titles
1.1.02.00.00	Excavation/construction	• Blasting and vibration • Geochemical alteration (excavation) • Groundwater chemistry (excavation) • Influx of oxidizing water
2.2.01.01.00	Excavation and construction-related changes in the adjacent host rock	• Disturbed rock zone • Mechanical effects – excavation/backfilling effects • Formation of cracks (host rock disturbed zone) • Damaged zone (host rock disturbed zone) • Excavation/backfilling effects on nearby rock • Enhanced rock fracturing • Creeping of rock mass, near-field • Disturbed zone (hydromechanical effects) • Excavation-induced changes in stress
2.2.01.05.00	Radionuclide transport in excavation disturbed zone	• Radionuclide retardation (excavation-disturbed zone) • Radionuclide release from EDZ

Table 10. Included/Excluded FEPs: Repository Perturbed THMC (continued)

YMP Primary FEP Number	Primary FEP Title	Secondary FEPs Titles
2.2.07.10.00	Condensation zone forms around drifts	• Condensation cap forms above repository • Formation of condensate over individual containers • Formation of condensate over individual panels • Formation of condensate over entire repository • Shedding of condensate cap over one drift to another drift • Vault geometry
2.2.07.11.00	Return flow from condensation cap / resaturation of dry-out zone	• Auto-catalytic drainage of locally saturated flow thru condensation cap* • Resaturation, near-field rock • Return of condensate to same panel • Resaturation of dry-out zone is affected by vapor flow • Resaturation of dry-out zone is affected by liquid under capillary forces • Unsaturated flow plume returns flow from the condensation cap
2.2.08.01.00	Groundwater chemistry / composition in UZ and SZ	• Groundwater chemistry (in geosphere) • Deep saline water intrusion • Interface different waters (in geosphere) • Water chemistry in near-field rock • Freshwater intrusion (in geosphere) • Changes in groundwater Eh • Changes in groundwater pH • Oxidizing conditions • Groundwater composition • pH-deviations • Changes of groundwater chemistry in nearby rock • Effects at saline-freshwater interface • Chemical gradients • Non-radioactive solute plume in geosphere • Mineralogy (host rock)

Table 10. Included/Excluded FEPs: Repository Perturbed THMC (continued)

YMP Primary FEP Number	Primary FEP Title	Secondary FEPs Titles
2.2.08.02.00	Radionuclide transport occurs in a carrier plume in geosphere	• Locally saturated carrier plume forms (in geosphere) • Unsaturated carrier plume forms (in geosphere) • Precipitation/dissolution (release/migration factors)
2.2.08.03.00	Geochemical interactions in geosphere (dissolution, precipitation, weathering) and effects on radionuclide transport	• Far-field transport: changes in groundwater chemistry and flow direction • Effects of dissolution (in geosphere) • Rock property changes (in geosphere) • Hydraulic properties-evolution
		• Dissolution of fracture fillings/precipitation (in geosphere) • Weathering of flow paths (in geosphere) • Fracture mineralization and weathering (in geosphere) • Precipitation and dissolution (release/migration factors) • Chemical precipitation (release/migration factors) • Dissolution, precipitation, and crystallization (release/migration factors) • Kinetics of precipitation and dissolution (release/migration factors) • Speciation (contaminant speciation and solubility) • Recrystallization (contaminant speciation and solubility) • Kinetics of speciation (contaminant speciation and solubility) • Groundwater chemistry (sorption/desorption process)
2.2.08.05.00	Osmotic processes	None
2.2.08.06.00	Complexation in geosphere	None
2.2.08.07.00	Radionuclide solubility limits in the geosphere	• Solubility limits/colloid formation
2.2.09.01.00	Microbial activity in geosphere	• Microbes (in geosphere) • Microbial activity (in geosphere) • Far-field transport: biogeochemical changes • Bacteria and microbes in soil • Chemical transformations (biological processes)

Table 10. Included/Excluded FEPs: Repository Perturbed THMC (continued)

YMP Primary FEP Number	Primary FEP Title	Secondary FEPs Titles
2.2.10.01.00	Repository-induced thermal effects in geosphere	• Temperature, far-field • Temperature, near-field rock • Thermal effects on groundwater flow • Groundwater evolution • Thermal effects on material properties (in waste and engineered barrier system) • Thermal effects: rock mass changes • Thermal effects: hydrogeological changes
2.2.10.04.00	Thermo-mechanical alteration of fractures near repository	• Thermal expansion closes most fractures close to repository • Thermally-induced fracturing around containers creates a capillary barrier • Host rock fracture aperture changes
2.2.10.05.00	Thermo-mechanical alteration of rocks above and below the repository	• Thermal expansion of rocks below repository opens fractures in Paintbrush nonwelded • Thermo-mechanical alteration of surface infiltration
2.2.10.06.00	Thermo-chemical alteration (solubility, speciation, phase changes, precipitation/dissolution)	• Silica phase changes (accompanied by volume change) occur due to elevated temperature • Thermochemical change • Alteration of rock properties because of 2-phase flow • Heat-induced chemical reactions plug small fractures; flow is preferentially redirected to large fractures • Alteration of minerals to clays (in geosphere) • Calcite precipitation in hot regions produces fluids depleted in calcite which dissolve calcite below the repository • Precipitates from dissolved constituents of tuff and repository materials form by evaporation during thermal period
2.2.10.07.00	Thermo-chemical alteration of the Calico Hills unit	None

Table 10. Included/Excluded FEPs: Repository Perturbed THMC (continued)

YMP Primary FEP Number	Primary FEP Title	Secondary FEPs Titles
2.2.10.09.00	Thermo-chemical alteration of the Topopah Spring basal vitrophyre	• Formation of perched water on the altered Topopah Spring basal vitrophyre • Sorption of contaminants by the altered Topopah Spring basal vitrophyre • Redirection of transport paths by the altered Topopah Spring basal vitrophyre • Sorption of actinides on altered Topopah Spring basal vitrophyre • Alteration of the Topopah Spring basal vitrophyre

6.8.1 Excavation/Construction (1.1.02.00.00)

YMP Primary FEP Description: This category contains FEPs related to the excavation of the underground regions of the repository, and effects of this excavation on the long-term behavior of the engineered and natural barriers. Excavation-related effects include changes to rock properties due to boring and blasting and geochemical changes to rock and groundwater.

Disposition: Include the effects of stress relief and ground support on drift seepage. Exclude changes in water chemistry on the basis of low consequence.

Screening Argument: This FEP concerns the changes in the host rock environment immediately surrounding the waste emplacement drifts. Changes are expected in the rock fracture properties due to excavation disturbance and stress relief around the opening. Also, the ground support for the emplacement drifts can affect water flow patterns in the immediate vicinity of the drift and can affect the aqueous geochemistry in the drift environment and along flow pathways from the drift to the water table. Changes in fracture properties due to excavation disturbance, stress relief, and ground support are included in the analyses for drift seepage (CRWMS M&O 2000g; Section 6). Changes in water chemistry entering the drift due to excavation/construction effects are expected to be negligible. Therefore, this aspect is excluded on the basis of low consequence.

6.8.2 Excavation and Construction-Related Changes in the Adjacent Host Rock (2.2.01.01.00)

YMP Primary FEP Description: Excavation will produce some disturbance of the rocks surrounding the drifts due to stress relief. Stresses associated directly with excavation (e.g., boring and blasting operations) may also cause some changes in rock properties. Properties that may be affected include rock strength, fracture spacing and block size, and hydrologic properties such as permeability.

Disposition: Include the effects of stress relief and ground support on drift seepage. Exclude changes in water chemistry on the basis of low consequence.

Screening Argument: This FEP concerns the effects of excavation and construction-related disturbances in the host rock adjacent to the waste emplacement drifts. This is basically the same issue raised in Section 6.8.1. Changes are expected in the rock fracture properties due to excavation disturbance and stress relief around the opening. Also, the ground support for the emplacement drifts can affect water flow patterns in the immediate vicinity of the drift and can affect the aqueous geochemistry in the drift environment and along flow pathways from the drift to the water table. Changes in fracture properties due to excavation disturbance, stress relief, and ground support are included in the analyses for drift seepage (CRWMS M&O 2000g; Section 6). Changes in water chemistry entering the drift due to excavation/construction effects are expected to be negligible. Therefore, this aspect is excluded on the basis of low consequence.

6.8.3 Radionuclide Transport in Excavation Disturbed Zone (2.2.01.05.00)

YMP Primary FEP Description: Radionuclide transport through the excavation disturbed zone may differ from transport in the waste and EBS and the undisturbed host rock. Transport processes such as dissolution and precipitation, sorption, and colloid filtration should be considered.

Disposition: Exclude on the basis of low consequence.

Screening Argument: This FEP refers to the effects of altered fracture properties in the disturbed zone immediately surrounding the waste emplacement drifts on radionuclide transport. The effects of changes in fracture aperture on radionuclide transport were investigated at the mountain-scale (CRWMS M&O 2000e; Section 6). The results of this analysis find that the transport behavior is relatively insensitive to changes in fracture aperture by as much as a factor of 10. Therefore, the effects of locally disturbed fractures should have even less effect on radionuclide transport processes. Precipitation of aqueous radionuclides and colloid filtration in fractures are conservatively ignored in the TSPA transport model. Therefore, the effects of this FEP on TSPA are excluded on the basis of low consequence.

6.8.4 Condensation Zone Forms Around Drifts (2.2.07.10.00)

YMP Primary FEP Description: Condensation of the 2-phase flow generated by repository heat forms in the rock where the temperature drops below the local vaporization temperature. Waste package emplacement geometry and thermal loading will affect the scale at which condensation caps form (over waste packages, over panels, or over the entire repository), and the extent to which "shedding" will occur as water flows from the region above one drift to the region above another drift or into the rock between drifts.

Disposition: Exclude mountain-scale effects on the basis of low consequence. Include effects on drift seepage.

Screening Argument: Condensation is included in the thermal-hydrologic process model that describes the effects of waste heat on the potential repository and surrounding natural system (CRWMS M&O 2000f; Section 6). The flow behavior predicted by the thermal-hydrologic models are incorporated into drift seepage model abstraction (CRWMS M&O 2000o; Section 6). The drift-scale flow model abstraction accounts for flow volumes and flow focusing under flow conditions perturbed by thermal-hydrologic flow processes. The effects of these processes on mountain-scale flow are expected to be minimal (Assumption 13). Therefore, this aspect of the FEP is excluded from TSPA based on low consequence.

6.8.5 Return Flow from Condensation Cap / Resaturation of Dry-Out Zone (2.2.07.11.00)

YMP Primary FEP Description: Following the peak thermal period, water in the condensation cap (see FEP 2.2.07.10.00) may flow downward into the drifts. Influx of cooler water from above, such as might occur from episodic flow, may accelerate return flow from the condensation cap by lowering temperatures below the condensation point. Percolating groundwater (distinct from water mobilized from the condensation cap) will also contribute to resaturation of the dry out zone. Vapor flow, as distinct from liquid flow by capillary processes, may also contribute. Water chemistry in the resaturation period may be affected by processes in the condensation cap and dry-out zone.

Disposition: Exclude mountain-scale effects on the basis of low consequence. Include effects on drift seepage.

Screening Argument: The effects of condensation formation is included in the TSPA as discussed in the previous FEP (2.2.07.10.00). Resaturation of the dry-out zone is included in the analyses treating thermal-hydrologic processes (CRWMS M&O 2000f; Section 6) and the model abstraction for drift seepage (CRWMS M&O 2000o; Section 6) and coupled-processes. The effects on mountain-scale flow are expected to be minimal (Assumption 13). Therefore, this aspect of the FEP is excluded from TSPA based on low consequence. The effects of episodic transient infiltration on resaturation are expected to be minimal because episodic transient flow is damped out in the Paintbrush nonwelded hydrogeologic unit (see Section 6.3.5).

6.8.6 Groundwater Chemistry / Composition in UZ And SZ (2.2.08.01.00)

YMP Primary FEP Description: Chemistry and other characteristics of groundwater in the saturated and unsaturated zones may affect groundwater flow and radionuclide transport. Groundwater chemistry and other characteristics, including temperature, pH, Eh, ionic strength, and major ionic concentrations, may vary spatially throughout the system as a result of different rock mineralogy, and may also change through time, as a result of the evolution of the disposal system or from mixing with other waters.

Disposition: Include the effects of ambient-condition geochemistry. Exclude changes in geochemical conditions on the basis of low consequence.

Screening Argument: As discussed in Section 6.1.15, ambient-condition geochemical effects are included in the TSPA model for radionuclide sorption (CRWMS M&O 2000j; Section 6 and 2000q; Section 6). Important changes to groundwater chemistry in the post-closure repository environment are likely to be the result of the thermo-chemical interactions of the repository with the water and minerals in the unsaturated zone (Assumption 10). The thermo-chemical interactions that will occur in the repository environment have been studied with respect to effects on the seepage water entering the waste emplacement drifts (CRWMS M&O 2000s; Section 6). Chemical composition and hydrologic properties were found in this study to change only slightly as a result of these interactions. This includes the effects of dissolution and precipitation of minerals in fractures and matrix. Because these interactions were studied in the vicinity of the waste emplacement drifts where thermo-chemical interactions are expected to be more severe, it is assumed that the effects of thermo-chemical interactions along the pathways of aqueous radionuclides in the unsaturated zone will also be small (Assumption 11). Therefore the effects of these changes are excluded from TSPA on the basis of low consequence.

6.8.7 Radionuclide Transport Occurs in a Carrier Plume in Geosphere (2.2.08.02.00)

YMP Primary FEP Description: Radionuclide transport occurs in a carrier plume in the geosphere. Transport may be as dissolved or colloidal species, and transport may occur in both the unsaturated and saturated zone. See also FEPs 2.1.09.01.00 (carrier plume forms in waste and EBS), 2.2.08.01.00 (groundwater chemistry / composition) and 2.2.08.03.00 (geochemical interactions).

Disposition: Exclude on the basis of low consequence.

Screening Argument: This FEP is similar in content to the one discussed in Section 6.8.6. The thermo-chemical interactions that will occur in the repository environment have been studied with respect to effects on the seepage water entering the waste emplacement drifts (CRWMS M&O 2000s; Section 6). Chemical composition and hydrologic properties were found in this study to change only slightly as a result of these interactions. This includes the effects of dissolution and precipitation of minerals in fractures and matrix. Because these interactions were studied in the vicinity of the waste emplacement drifts where thermo-chemical interactions are expected to be more severe, it is assumed that the effects of thermo-chemical interactions along the pathways of aqueous radionuclides in the unsaturated zone will also be small (Assumption 11). Therefore the effects of these changes are excluded from TSPA on the basis of low consequence.

6.8.8 Geochemical Interactions in Geosphere (Dissolution, Precipitation, Weathering) and Effects on Radionuclide Transport (2.2.08.03.00)

YMP Primary FEP Description: Geochemical interactions may lead to dissolution and precipitation of minerals along the groundwater flow path, affecting groundwater flow, rock properties and sorption on contaminants. These interactions may result from the evolution of disposal system or from external processes such as weathering. Effects on hydrologic flow properties of the rock, radionuclide solubilities, sorption processes, and colloidal transport are relevant. Kinetics of chemical reactions should be considered in the context of the time-scale of concern. See also FEP 2.2.08.01.00 for a discussion of groundwater chemistry and composition, FEP 2.2.08.07.00 for a discussion of solubility limits in the geosphere, FEP 2.2.08.09.00 for a discussion of sorption in the geosphere, and FEPs 2.2.08.10.00 and 2.2.08.10.01 for a discussion of colloidal transport .

Disposition: Exclude on the basis of low consequence.

Screening Argument: This FEP is similar in content to the one discussed in Section 6.8.7. The thermo-chemical interactions that will occur in the repository environment have been studied with respect to effects on the seepage water entering the waste emplacement drifts (CRWMS M&O 2000s; Section 6). Chemical composition and hydrologic properties were found in this study to change only slightly as a result of these interactions. This includes the effects of dissolution and precipitation of minerals in fractures and matrix. Because these interactions were studied in the vicinity of the waste emplacement drifts where thermo-chemical interactions are expected to be more severe, it is assumed that the effects of thermo-chemical interactions along the pathways of aqueous radionuclides in the unsaturated zone will also be small (Assumption 11). Therefore the effects of these changes are excluded from TSPA on the basis of low consequence.

6.8.9 Osmotic Processes (2.2.08.05.00)

YMP Primary FEP Description: Osmotic processes in response to chemical gradients could affect radionuclide transport in the geosphere. See also FEP 2.2.08.08.00, matrix diffusion.

Disposition: Exclude on the basis of low consequence.

Screening Argument: Osmosis would tend to cause water from fractures to flow into matrix, if the matrix presents a suitable barrier to the migration of dissolved salts. This process is expected to be negligible at Yucca Mountain and is conservatively ignored in TSPA.

6.8.10 Complexation in Geosphere (2.2.08.06.00)

YMP Primary FEP Description: Complexing agents such as humic and fulvic acids present in natural groundwaters could affect radionuclide transport. See also FEP 2.1.09.13.00 for a discussion of complexing agents in the waste and EBS.

Disposition: Include effects of ambient-condition complexation. Exclude effects of changes to complex formation due to changes in geochemical conditions on the basis of low consequence.

Screening Argument: This FEP refers to the geochemical interactions between ligands and metal ions, particularly radionuclides. Complexation is expected to occur under post-closure repository conditions. For ambient conditions this phenomenon is implicitly included in the radionuclide sorption coefficients (see Section 6.1.15). Thermo-chemical interactions due to repository heat and materials interactions may alter the geochemical environment, including the ligands that interact with radionuclides. Although the effects of ligands on radionuclides were not investigated in the near-field thermo-chemical modeling study (CRWMS M&O 2000s; Section 6), the general results of the modeling study indicate that the changes in geochemistry driven by thermo-chemical interactions are not large. If changes in the geochemistry are generally small, then the effects of ligands on radionuclide transport should also be small (Assumption 11). Therefore, this FEP is excluded from TSPA on the basis of low consequence.

6.8.11 Radionuclide Solubility Limits in the Geosphere (2.2.08.07.00)

YMP Primary FEP Description: Solubility limits for radionuclides may different in geosphere groundwater than in the water in the waste and EBS. See also FEP 2.2.08.01.00 for a discussion of groundwater chemistry and FEP 2.1.09.04.00 for a discussion of solubility limits in the waste and EBS.

Disposition: Exclude on the basis of low consequence.

Screening Argument: This FEP is conservatively ignored with respect to solubility reduction in the far-field; the effects of radionuclide precipitation are ignored in the far-field unsaturated zone transport problem for TSPA. The effects of colloid formation are accounted for in the colloid source term. Colloids are expected to be formed from the dissolution of glass waste and from natural colloidal materials. Radionuclides associated with colloids are assumed to be either irreversibly or reversibly attached to colloids (CRWMS M&O 2000q; Section 6 and CRWMS M&O 2000k; Section 6). Therefore, this FEP is excluded from TSPA on the basis of low consequence.

6.8.12 Microbial Activity in Geosphere (2.2.09.01.00)

YMP Primary FEP Description: Microbial activity in the geosphere may affect radionuclide mobility in rock and soil through colloidal processes, by influencing the availability of complexing agents, or by influencing groundwater chemistry. See also FEP 2.2.08.10.00 for a discussion of colloidal transport and 2.2.08.06.00 for a discussion of complexing agents.

Disposition: Exclude on the basis of low consequence.

Screening Argument: The effects of microbial activity and other dissolved organic matter are expected to have a negligible influence on repository performance due to the low amounts of such materials emplaced or generated in the post-closure repository environment (CRWMS M&O 2000y; Section 6) (Assumption 12). Colloidal activity, radionuclide speciation, and complexation are expected to be controlled by inorganic constituents generated by the waste forms or by natural inorganic ligands. Therefore, this FEP is excluded from TSPA on the basis of low consequence.

6.8.13 Repository-Induced Thermal Effects in Geosphere (2.2.10.01.00)

YMP Primary FEP Description: Thermal effects in the geosphere could affect the long-term performance of the disposal system. Thermal effects are most important in waste, engineered barrier system, and the disturbed zone surrounding the excavation. See FEPs 2.1.11.00.00 and 2.2.01.00.00 for discussions of this region. See other FEPs in this section for specific discussions of thermal effects in geosphere, including effects on saturated and unsaturated groundwater flow, mechanical properties, and chemical effects.

Disposition: Exclude mountain-scale thermo-chemical effects on the basis of low consequence. Include thermo-chemical effects on drift seepage.

Screening Argument: The effects of repository-induced thermal effects on flow are included for drift seepage (see Section 6.8.4). The effects on drift seepage chemistry are included. These effects are expected to be much less important for mountain-scale flow, as discussed in Section 6.8.4. Any changes resulting from thermo-chemical effects are expected to be bounded by the results of the near-field thermo-chemical modeling study (CRWMS M&O 2000s; Section 6) (Assumption 11). The general results of the near-field thermo-chemical modeling study indicate that the changes in geochemistry driven by thermo-chemical interactions are not large. Furthermore, any thermo-chemical effects are expected to decrease with time as the thermal energy of the repository is spent. Radionuclide transport will be more important as time increases due to the large inventory of radionuclides that will become available over time. Therefore the repository-induced thermo-chemical effects at the mountain scale are excluded from TSPA on the basis of low consequence.

6.8.14 Thermo-Mechanical Alteration of Fractures Near Repository (2.2.10.04.00)

YMP Primary FEP Description: Heat from the waste causes thermal expansion of the surrounding rock, generating changes in the stress field that may change the material properties (both hydrologic and mechanical) of fractures in the rock. Cooling following the peak thermal period will also change the stress field, further affecting rock properties near the repository.

Disposition: Exclude on the basis of low consequence.

Screening Argument: The main compressive stresses caused by thermo-mechanical effects will occur during the period when temperatures are increasing. Drift seepage is not expected during this time period when temperatures are increasing because water is boiled and removed as vapor flow from the vicinity of the waste emplacement drifts. The effects of thermo-mechanical stress around the waste emplacement drifts are expected to be small by the time water is present to seep into the drifts (Assumption 14). Therefore, this FEP is excluded from TSPA on the basis of low consequence.

6.8.15 Thermo-Mechanical Alteration of Rocks Above and Below the Repository (2.2.10.05.00)

YMP Primary FEP Description: Thermo-mechanical compression at the repository produces tension-fracturing in the PTn and other units above the repository. These fractures alter unsaturated zone flow between the surface and the repository. Extreme fracturing may propagate to the surface, affecting infiltration. Thermal fracturing in rocks below the repository affects flow and radionuclide transport to the saturated zone.

Disposition: Exclude on the basis of low consequence.

Screening Argument: The effects of mechanical disturbance of fractures along radionuclide transport pathways is discussed in Section 6.7.1. The conclusion reached in that section is that the effects of changes to fracture aperture or spacing on radionuclide transport is expected to be negligible. In this case, the disturbance is caused by thermo-mechanical effects rather than a seismic event. However, the conclusions reached in Section 6.7.1 are also applicable here. Therefore, this FEP is excluded from TSPA on the basis of low consequence.

The effects of changes in fracture properties above the potential repository could influence the pattern of flow from the surface to the waste emplacement drifts. Changes in fracture properties could lead to focused flow on waste emplacement drifts. The effects of focused flow have been included in the drift seepage model (see Section 6.1.10).

6.8.16 Thermo-Chemical Alteration (Solubility, Speciation, Phase Changes, Precipitation/Dissolution) (2.2.10.06.00)

YMP Primary FEP Description: Thermal effects may affect radionuclide transport directly by causing changes radionuclide speciation and solubility in the UZ and SZ, or indirectly, by causing changes in host rock mineralogy that affect the flow path. Relevant processes include volume effects associated with silica phase changes, precipitation and dissolution of fracture-filling minerals (including silica and calcite), and alteration of zeolites and other minerals to clays.

Disposition: Exclude on the basis of low consequence.

Screening Argument: This FEP raises some issues already addressed in Section 6.8.11. This FEP is conservatively ignored with respect to solubility reduction in the far-field; the effects of radionuclide precipitation are ignored in the far-field unsaturated zone transport problem for TSPA. The effects of colloid formation are accounted for in the colloid source term. Colloids are expected to be formed from the dissolution of glass waste and from natural colloidal materials. Radionuclides associated with colloids are assumed to be either irreversibly or reversibly attached to colloids (CRWMS M&O 2000q; Section 6 and CRWMS M&O 2000k; Section 6). The near-field thermal-chemical analysis indicates only small changes in aqueous geochemistry and mineralogy as a result of these coupled processes (CRWMS M&O 2000s; Section 6). Therefore, far-field changes are likewise expected to be small (Assumption 11), including mineral precipitation/dissolution and alteration of minerals such as zeolites and clays. Therefore, this FEP is excluded from TSPA on the basis of low consequence and low probability.

6.8.17 Thermo-Chemical Alteration of the Calico Hills Unit (2.2.10.07.00)

YMP Primary FEP Description: Fracture pathways in the Calico Hills are altered by the thermal and chemical properties of the water flowing out of the repository.

Disposition: Exclude on the basis of low consequence.

Screening Argument: The near-field thermal-chemical analysis indicates only small changes in aqueous geochemistry and mineralogy as a result of these coupled processes (CRWMS M&O 2000s; Section 6). Therefore, far-field changes are likewise expected to be small (Assumption 11), including mineral precipitation/dissolution and alteration of minerals such as zeolites and clays. In particular, with respect to thermal alteration of zeolites, results of the 3D mountain-scale thermal-hydrologic calculations (CRWMS M&O 2000bb; Section 6.8.2.1) suggest that temperatures in the zeolite-bearing CHn will not be high enough to cause significant zeolite alteration. This FEP is excluded on the basis of low consequence.

6.8.18 Thermo-Chemical Alteration of the Topopah Spring Basal Vitrophyre (2.2.10.09.00)

YMP Primary FEP Description: Heating the Topopah Spring basal vitrophyre with water available causes alteration of the glasses to clays and zeolites. Possible effects include volume increases that plug fractures, changes in flow paths, creation of perched water zones, and an increase in the sorptive properties of the unit.

Disposition: Exclude on the basis of low consequence.

Screening Argument: The near-field thermal-chemical analysis indicates only small changes in aqueous geochemistry and mineralogy as a result of these coupled processes (CRWMS M&O 2000s; Section 6). Therefore, far-field changes are likewise expected to be small (Assumption 11), including mineral precipitation/dissolution and alteration of minerals such as zeolites and clays.. This FEP is excluded on the basis of low consequence.

7. CONCLUSIONS

This document presents the 515 FEPs associated with unsaturated zone flow and transport processes. These FEPs have been organized into 81 primary FEPs and associated 434 secondary FEPs. The 22 primary FEPs identified in Section 6.1, along with portions of primary FEPs identified in sections 6.2.1, 6.2.2, 6.2.4, 6.3.4, 6.3.5, 6.3.6, 6.3.7, 6.3.8, 6.7.1, 6.7.2, 6.7.9, 6.8.1, 6.8.2, 6.8.4, 6.8.5, 6.8.6, 6.8.10, and 6.8.13 are included in TSPA. The portions of these 18 FEPs not included, along with the remaining 41 primary FEPs, are excluded from TSPA based on arguments presented in this document. The 434 secondary FEPs associated with these primary FEPs are included or excluded based on the primary FEP arguments.

Some of the FEPs arguments for exclusion are based on assumptions that require further verification. All assumptions are given in Section 5, and the assumptions that require further verification are identified. Many of the FEP exclusion arguments that are based on assumptions requiring further verification are found in Section 6.8. This section concerns the effects of repository perturbed thermal-hydrologic-mechanical-chemical coupled processes. In particular, the arguments used to exclude the FEPs in Sections 6.8.4, 6.8.5, 6.8.6, 6.8.7, 6.8.8, 6.8.10, 6.8.12, 6.8.13, 6.8.14, 6.8.17, and 6.8.18 use assumptions that require verification. In addition, to these FEPs from Section 6.8, the FEP exclusion arguments used in Sections 6.3.5 and 6.3.8 are based on assumptions that require verification. If any of these assumptions cannot be verified, then additional modeling work will be required to include in TSPA the FEPs that have been excluded based on those assumptions.

This document and its conclusions may be affected by technical product input information that requires confirmation. Any changes to the document or its conclusions that may occur as a result of completing the confirmation activities will be reflected in subsequent revisions. The status of the input information quality may be confirmed by review of the Document Input Reference System database.

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SOFTWARE

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ATTACHMENT I

INCLUDED FEPS DESCRIPTIONS

PRIMARY YMP FEP NUMBER: 1.3.01.00.00
FEP NAME: Climate Change, Global

ORIGINATOR FEP DESCRIPTION: Global climate change refers to FEPs related to the possible future, and evidence for past, long term change of global climate. This is distinct from resulting changes that may occur at specific locations according to their regional setting and also climate fluctuations.

YMP PRIMARY FEP DESCRIPTION: Climate change may affect the long-term performance of the repository. This includes the effects of long-term change in global climate (e.g., glacial/interglacial cycles) and shorter-term change in regional and local climate. Climate is typically characterized by temporal variations in precipitation and temperature.

SECONDARY YMP FEP NUMBER: 1.3.01.00.01
FEP NAME: Climate change

ORIGINATOR FEP DESCRIPTION: The current climate may change to wetter, drier, warmer, cooler and/or permafrost conditions, affecting flow properties of the geosphere (including recharge volumes).

SECONDARY YMP FEP NUMBER: 1.3.01.00.02
FEP NAME: No ice age

ORIGINATOR FEP DESCRIPTION: This is a variation of ice age (not a specific feature, event or process on the merged list). However, no ice age puts special demands on how to treat the biosphere not to be confused with the base case scenario which assumes a steady biosphere.

SECONDARY YMP FEP NUMBER: 1.3.01.00.03
FEP NAME: Solar insolation

ORIGINATOR FEP DESCRIPTION: None

SECONDARY YMP FEP NUMBER: 1.3.01.00.04
FEP NAME: No ice age

ORIGINATOR FEP DESCRIPTION: None

SECONDARY YMP FEP NUMBER: 1.3.01.00.05
FEP NAME: Climate change: natural

ORIGINATOR FEP DESCRIPTION: Natural climate changes associated with Milankovitch cycles (external forcing processes) and leading to glacial/interglacial cycling. Natural climate change will have a direct effect on the biosphere in terms of ecology, and will indirectly affect the far-field by changing hydrogeological boundary conditions and, thus, influencing radionuclide transport.

SECONDARY YMP FEP NUMBER: 1.3.01.00.06
FEP NAME: Exit from glacial/interglacial cycling

ORIGINATOR FEP DESCRIPTION: Exit from individual glacial periods will cause large volumes of surface water to accumulate as some glaciers melt. Melt water, and its rate of production, have an important effect on surface environments, groundwater fluxes and flow directions.

SECONDARY YMP FEP NUMBER: 1.3.01.00.07
FEP NAME: Exit from glacial/interglacial cycling

ORIGINATOR FEP DESCRIPTION: A lengthening of individual glaciations or repeated glaciations may more rapidly exhume the repository.

SECONDARY YMP FEP NUMBER: 1.3.01.00.08
FEP NAME: Climatological (effects)

ORIGINATOR FEP DESCRIPTION: None

SECONDARY YMP FEP NUMBER: 1.3.01.00.09
FEP NAME: Climate change

ORIGINATOR FEP DESCRIPTION: There could be massive climate changes on the Shield due to anthropogenic and natural causes. Here the focus is on natural causes and in particular the occurrence of further continental glaciations.

SECONDARY YMP FEP NUMBER: 1.3.01.00.10
FEP NAME: Present-day climatic conditions

ORIGINATOR FEP DESCRIPTION: The present-day climate of northern Switzerland is described as cool and is representative of interglacial conditions.

SECONDARY YMP FEP NUMBER: 1.3.01.00.11
FEP NAME: Seasonality of climate

ORIGINATOR FEP DESCRIPTION: The degree of seasonality of climate is one factor that distinguishes the warm, seasonal humid climate from the warm equable humid climate. In the seasonal climate, marked seasonal variations in precipitation, run-off, erosion and groundwater recharge occur. In the equable climate more uniform conditions prevail.

SECONDARY YMP FEP NUMBER: 1.3.01.00.12
FEP NAME: Future climatic conditions

ORIGINATOR FEP DESCRIPTION: Paleo-evidence indicates that climatic conditions in northern Switzerland have varied greatly in the past. ... Climatic change is to be expected over the timescales relevant to repository performance as a result of natural processes and human activities e.g. greenhouse effect.

SECONDARY YMP FEP NUMBER: 1.3.01.00.13
FEP NAME: Warmer climate - arid

ORIGINATOR FEP DESCRIPTION: An arid climate is characterized by high mean annual temperatures, low mean annual rainfall with episodic precipitation; very low effective moisture; through-flowing major rivers (e.g., Rhine), with reduced run-off. etc.

SECONDARY YMP FEP NUMBER: 1.3.01.00.14
FEP NAME: Warmer climate - seasonal humid

ORIGINATOR FEP DESCRIPTION: The climate could become significantly warmer than the present day exhibiting a marked seasonality between warm, humid, rainy seasons and cool, dry seasons (monsoon-like). Evapotranspiration is moderate and there is moderate effective moisture. Streams are perennial with marked seasonal variations is run-off. Vegetation cover is moderate. The onset of the wet season is associated with the maximum erosion (both fluvial down cutting and denudation). Such a climate is possible if the greenhouse effect was dominant and glaciation ended.

SECONDARY YMP FEP NUMBER: 1.3.01.00.15
FEP NAME: Warmer climate - equable humid

ORIGINATOR FEP DESCRIPTION: This climate state is characterized by high temperatures, precipitation and moderate evapotranspiration with minor seasonality. This results in high effective moisture, and a well defined network of perennial streams with high run-off. Vegetation cover is complete and continuous. Such a climate may occur if the greenhouse effect becomes significant and glaciation ends.

SECONDARY YMP FEP NUMBER: 1.3.01.00.16
FEP NAME: Climate change (effects on repository)

ORIGINATOR FEP DESCRIPTION: Changes to the current climate may affect the performance of the vault. For example, increased or decreased rates of meteoric precipitation may affect the volume and rate of groundwater flow past the disposal vault.

SECONDARY YMP FEP NUMBER: 1.3.01.00.17
FEP NAME: Global effects

ORIGINATOR FEP DESCRIPTION: The vault behavior might be modified by global effects such as movement of molten material, climate change, greenhouse warming, drought and flooding.

SECONDARY YMP FEP NUMBER: 1.3.01.00.18
FEP NAME: Climate (meteorology)

ORIGINATOR FEP DESCRIPTION: A wide variety of climatic factors, such as temperature, precipitation and wind speed, can directly or indirectly influence the behavior and transport of contaminants in the environment. For example, temperature influences heating fuel needs, which in turn may influence radionuclide concentration in indoor air and the inhalation dose to humans. Etc

SECONDARY YMP FEP NUMBER: 1.3.01.00.19
FEP NAME: Seasons (meteorology)

ORIGINATOR FEP DESCRIPTION: Seasons on the Shield affect many aspects of the natural and human environments. Because of temperature changes that lead to freezing, photosynthesis, which is at the bottom of most food webs, comes to a virtual standstill during the winter. etc.

SECONDARY YMP FEP NUMBER: 1.3.01.00.20
FEP NAME: Temperature (meteorology)

ORIGINATOR FEP DESCRIPTION: Temperatures at the WIPP site are moderate with annual temperature of about 63 F. Temperature is an important control on the amount of recharge that reaches the groundwater system and is accounted for in performance assessment calculations by use of a sampled parameter for scaling flow velocity in the Culebra.

SECONDARY YMP FEP NUMBER: 1.3.01.00.21
FEP NAME: Climate change (meteorology)

ORIGINATOR FEP DESCRIPTION: Climate changes are instigated by changes in the earth's orbit, which affect the amount of insolation, and by feedback mechanisms within the atmosphere and hydrosphere.

PRIMARY YMP FEP NUMBER: 1.3.07.02.00
FEP NAME: Water table rise

ORIGINATOR FEP DESCRIPTION: Regionally higher water tables create discharge points closer to the repository, reducing the distance to the accessible environment. The rise in the regional water table floods the repository.

YMP PRIMARY FEP DESCRIPTION: Climate change could produce increased infiltration, leading to a rise in the regional water table, possibly affecting the release and exposure pathways from the repository. A regionally higher water table and change in flow patterns might move discharge points closer to the repository, or flood the repository.

SECONDARY YMP FEP NUMBER: 1.3.07.02.01
FEP NAME: Short circuit of a flow barrier in the saturated zone because of a water table rise

ORIGINATOR FEP DESCRIPTION: A higher water table short-circuits a flow barrier in the saturated zone, changing the pattern of flow.

PRIMARY YMP FEP NUMBER: 2.1.08.01.00
FEP NAME: Increased unsaturated water flux at the repository

ORIGINATOR FEP DESCRIPTION: An increase in infiltration due to climate change at the repository site increases the unsaturated flux through the repository.

YMP PRIMARY FEP DESCRIPTION: An increase in the unsaturated water flux at the repository affects thermal, hydrologic, chemical, and mechanical behavior of the system. Extremely rapid influx could reduce temperatures below the boiling point during part or all of the thermal period. Increases in flux could result from climate change, but the cause of the increase is not an essential part of the FEP.

SECONDARY YMP FEP NUMBER: 2.1.08.01.01
FEP NAME: Waste container is thermally quenched by rapid influx of water

ORIGINATOR FEP DESCRIPTION: The local influx of water is sufficient to quench (reduce the surface temperature below vaporization) the waste containers it surrounds.

PRIMARY YMP FEP NUMBER: 2.1.08.02.00
FEP NAME: Enhanced influx (Philip's drip)

ORIGINATOR FEP DESCRIPTION: Philip's drip is a mechanism for focusing unsaturated flow to an underground opening and producing local saturation.

YMP PRIMARY FEP DESCRIPTION: An opening in unsaturated rock alters the hydraulic potential, affecting local saturation around the opening and redirecting flow. Some of the flow is directed to the opening where it is available to seep into the opening.

PRIMARY YMP FEP NUMBER: 2.2.03.01.00
FEP NAME: Stratigraphy

ORIGINATOR FEP DESCRIPTION: Stratigraphic information (thickness and lateral extent) is important input to the performance assessment. etc.

YMP PRIMARY FEP DESCRIPTION: Stratigraphic information is necessary information for the performance assessment. This information should include identification of the relevant rock units, soils and alluvium, and their thicknesses, lateral extents, and relationships to each other. Major discontinuities should be identified.

SECONDARY YMP FEP NUMBER: 2.2.03.01.01
FEP NAME: Mesozoic sedimentary cover

ORIGINATOR FEP DESCRIPTION: A Mesozoic sedimentary cover overlies, in part, the crystalline basement of Northern Switzerland, as well as the Permo-Carboniferous Trough (PCT) of Northern Switzerland. The Mesozoic cover consists of a heterogeneous sequence of strata, of variable thickness, that are subhorizontal and relatively undisturbed tectonically. etc.

SECONDARY YMP FEP NUMBER: 2.2.03.01.02
FEP NAME: Permo-Carboniferous Trough

ORIGINATOR FEP DESCRIPTION: During the Variscan orogeny, the crystalline basement underwent extensive deformation. A graben structure, the Permo-Carboniferous Trough of Northern Switzerland, formed during the late stage of this orogeny(around 315-245 million years ago). Etc. Re: SZ flow system.

SECONDARY YMP FEP NUMBER: 2.2.03.01.03
FEP NAME: Brine reservoirs

ORIGINATOR FEP DESCRIPTION: Units of interest to the WIPP project below the Salado are the Bell Canyon and the Castile. These units have quite different hydrologic characteristics. In part of the area around WIPP, the Castile has been significantly deformed and there are pressurized brines associated with the deformed areas.

PRIMARY YMP FEP NUMBER: 2.2.03.02.00
FEP NAME: Rock properties of host rock and other units

ORIGINATOR FEP DESCRIPTION: Expected features of the rock that should be modeled include porosity, tortuosity, permeability, active (open) fracture joints or zones, inhomogeneities and structures such as layers or zones of different rock. etc.

YMP PRIMARY FEP DESCRIPTION: Physical properties such as porosity and permeability of the relevant rock units, soils, and alluvium are necessary for the performance assessment. Possible heterogeneities in these properties should be considered.

SECONDARY YMP FEP NUMBER: 2.2.03.02.01
FEP NAME: Rock heterogeneity (host rock)

ORIGINATOR FEP DESCRIPTION: None

SECONDARY YMP FEP NUMBER: 2.2.03.02.02
FEP NAME: LPD effective hydraulic properties

ORIGINATOR FEP DESCRIPTION: The crystalline low permeability domain (LPD) consists of volume(s) of crystalline rock, generally at depths greater than 400-600 m below the upper surface of the crystalline basement, whose average effective hydraulic conductivity is small (generally less than 10-10m/s).

SECONDARY YMP FEP NUMBER: 2.2.03.02.03
FEP NAME: MWCF effective hydraulic properties

ORIGINATOR FEP DESCRIPTION: The crystalline basement of Areas West (LPD and HPD) and East is intersected to below repository depth by major, subvertical regional faults of first and second order. ... Some of these faults may be water-conducting (major water-conducting faults MWCF), with a higher hydraulic conductivity than the LPD. etc.

SECONDARY YMP FEP NUMBER: 2.2.03.02.04
FEP NAME: HPD effective hydraulic properties

ORIGINATOR FEP DESCRIPTION: The hydraulic properties of the crystalline basement are controlled by the properties of the small-scale water-conducting features which dissect it. In both Area West and Area East, the transmissivity and density of these features, and therefore of the hydraulic conductivity of the rock through which they pass, undergoes an abrupt decrease at depths greater than 400-600 m below the upper surface of the crystalline basement. etc.

SECONDARY YMP FEP NUMBER: 2.2.03.02.05
FEP NAME: Properties of far-field rock

ORIGINATOR FEP DESCRIPTION: Refers to the hydrological, mineralogical, mechanical, thermal and gas transport properties of the far-field rock which are of importance to radionuclide transport in the rock. Due to various processes and events, the properties may change with time.

PRIMARY YMP FEP NUMBER: 2.2.07.01.00
FEP NAME: Locally saturated flow at bedrock/alluvium contact

ORIGINATOR FEP DESCRIPTION: In washes in arid areas, infiltration can descend to the alluvium/bedrock interface and then proceed down the wash at that interface as a saturated flow system distant from the surface and distinct from the local water table.

YMP PRIMARY FEP DESCRIPTION: In washes in arid areas, infiltration can descend to the alluvium/bedrock interface and then proceed down the wash at that interface as a saturated flow system distant from the surface and distinct from the local water table.

PRIMARY YMP FEP NUMBER: 2.2.07.02.00
FEP NAME: Unsaturated groundwater flow in geosphere

ORIGINATOR FEP DESCRIPTION: The units above the Rustler Formation at the WIPP site are predominantly unsaturated. There was no inflow of water from the Dewey Lake into the WIPP shafts after they were completed and prior to their lining, indicating unsaturated conditions or low transmissivity. etc.

YMP PRIMARY FEP DESCRIPTION: Groundwater flow occurs in unsaturated rocks in most locations above the water table at Yucca Mountain, including at the location of the repository. See other FEPs in this section for discussions of specific issues related to unsaturated flow. See FEPs 2.2.07.03.00 (capillary rise), 2.2.07.04.00 (focussing of unsaturated flow), 2.2.07.05.00 (effects of episodic infiltration), 2.2.07.07 (perched water), 2.2.07.08.00 (fracture flow), 2.2.07.09.00 (matrix imbibition), 2.2.07.10.00 (condensation zone forms), 2.2.07.11.00 (return flow from condensation zone), and 2.2.10.10.00 (bouyant flow / heat pipes).

SECONDARY YMP FEP NUMBER: 2.2.07.02.01
FEP NAME: Unsaturated rock

ORIGINATOR FEP DESCRIPTION: Portions of the geosphere may be naturally unsaturated or become unsaturated due to dewatering during construction of the vault. Consequently rock temperatures may rise and an unsaturated transport may be important.

SECONDARY YMP FEP NUMBER: 2.2.07.02.02
FEP NAME: Soil depth

ORIGINATOR FEP DESCRIPTION: Soil depth refers to the distance between the soil surface down to the water table. ... Contaminants may move up and down the soil profile through capillary rise and leaching.

PRIMARY YMP FEP NUMBER: 2.2.07.03.00
FEP NAME: Capillary rise

ORIGINATOR FEP DESCRIPTION: Capillary rise involves the drawing up of soil water, above the water table, in continuous pores of the soil until the suction gradient is balanced by the gravitational pull downward.

YMP PRIMARY FEP DESCRIPTION: Capillary rise involves the drawing up of water, above the water table or above locally saturated zones, in continuous pores of the unsaturated zone until the suction gradient is balanced by the gravitational pull downward. Capillary rise may provide a mechanism for radionuclides to reach the surface environment in locations where the water table is shallow.

SECONDARY YMP FEP NUMBER: 2.2.07.03.01
FEP NAME: Capillary rise (near surface hydrology)

ORIGINATOR FEP DESCRIPTION: Capillary rise is the process by which solutes may move upwards through the soil profile from the water table (in the aquifer), under the following conditions:(1) Evapotranspiration (during a part of the year) exceeds precipitation; (2) the storage capacity of the soil is insufficient to match Evapotranspiration minus precipitation;(3) the soil texture is sufficiently fine for capillaries to be filled with water, (4) the water table is sufficiently near to the soil surface for the existence of continuous capillary water between the aquifer and surface.

PRIMARY YMP FEP NUMBER: 2.2.07.04.00
FEP NAME: Focusing of unsaturated flow (fingers, weeps)

ORIGINATOR FEP DESCRIPTION: The natural variation of hydrologic properties produces heterogeneities and local saturation which feeds locally saturated flow. That is, a uniform distribution of infiltration breaks up into localized flow fingers which feed fractures. Or, unsaturated flow reaches a flow barrier (a zone of reduced permeability) where the water accumulates or perches and continues as a saturated plume.

YMP PRIMARY FEP DESCRIPTION: Unsaturated flow can differentiate into zones of greater and lower saturation (fingers) that may persist as preferential flow paths. Heterogeneities in rock properties, including fractures and faults, may contribute to focussing. Focussed flow may become locally saturated.

SECONDARY YMP FEP NUMBER: 2.2.07.04.01
FEP NAME: Effects of preferential flow paths

ORIGINATOR FEP DESCRIPTION: The hydrogeologic properties of the Culebra are spatially variable. This variability, including the effects of preferential pathways, is accounted for in performance assessment calculations in the estimates of transmissivity and aquifer thickness.

SECONDARY YMP FEP NUMBER: 2.2.07.04.02
FEP NAME: Seeps and weeps form as a locally saturated flow system

ORIGINATOR FEP DESCRIPTION: Infiltration or condensate forms fingers which persist as locally saturated flow either through the matrix or through any connected set of fractures the fingers reach.

SECONDARY YMP FEP NUMBER: 2.2.07.04.03
FEP NAME: Fault control of fluid entrance to and movement away from the repository

ORIGINATOR FEP DESCRIPTION: Faults in the UZ act as conduits for fluids to move into the subsurface to interact with the repository and as conduits for fluids to leave the vicinity of the repository and be conducted to the SZ.

SECONDARY YMP FEP NUMBER: 2.2.07.04.04
FEP NAME: Fingering - contaminant transport in fingers in UZ

ORIGINATOR FEP DESCRIPTION: Fingering is the flow mechanism in the unsaturated zone whereby long fingers or zones of higher saturation persist in fields of less saturated rock. These flow fingers are able to transport contaminants.

PRIMARY YMP FEP NUMBER: 2.2.07.08.00
FEP NAME: Fracture flow in the unsaturated zone

ORIGINATOR FEP DESCRIPTION: Fractures act as conduits for fluids to move into the subsurface to interact with the repository and as conduits for fluids to leave the vicinity of the repository and be conducted to the SZ.

YMP PRIMARY FEP DESCRIPTION: Fractures or other analogous channels act as conduits for fluids to move into the subsurface to interact with the repository and as conduits for fluids to leave the vicinity of the repository and be conducted to the SZ.

SECONDARY YMP FEP NUMBER: 2.2.07.08.01
FEP NAME: Fracture flow (in geosphere)

ORIGINATOR FEP DESCRIPTION: Flow in the Culebra occurs within fractures, within vugs where they are connected by fractures, and to some extent within interparticle porosity where the porosity (and permeability) is high, such as chalky lenses. etc.

SECONDARY YMP FEP NUMBER: 2.2.07.08.02
FEP NAME: Extreme channel flow of oxidants and nuclides (in geosphere)

ORIGINATOR FEP DESCRIPTION: The water does not flow over the whole fracture plane. This fact is often noted by "channeling". (A lengthy discussion of what channeling is and how it might affect fracture transport follows.)

PRIMARY YMP FEP NUMBER: 2.2.07.09.00
FEP NAME: Matrix imbibition in the unsaturated zone

ORIGINATOR FEP DESCRIPTION: Flow down fractures in the phreatic zone is imbibed into the surrounding rock matrix.

YMP PRIMARY FEP DESCRIPTION: Water flowing in fractures or other channels in the unsaturated zone is imbibed into the surrounding rock matrix. This may occur during steady flow, episodic flow, or into matrix pores that have been dried out during the thermal period.

SECONDARY YMP FEP NUMBER: 2.2.07.09.01
FEP NAME: Resaturation due to matrix imbibition of episodic fracture flow

ORIGINATOR FEP DESCRIPTION: Episodic fracture flow, of infiltrating waters, is imbibed by the matrix which was dried out (reduced saturation) during the thermal period.

PRIMARY YMP FEP NUMBER: 2.2.08.04.00
FEP NAME: Redissolution of Precipitates Directs More Corrosive Fluids to Containers

ORIGINATOR FEP DESCRIPTION: Redissolution of precipitates which have plugged pores as a result of evaporation of ground water in the hot zone, produces a pulse of fluid reaching the waste containers when gravity-driven flow resumes, which is more corrosive than the original fluid in the rock.

YMP PRIMARY FEP DESCRIPTION: Redissolution of precipitates which have plugged pores as a result of evaporation of ground water in the hot zone, produces a pulse of fluid reaching the waste containers when gravity-driven flow resumes, which is more corrosive than the original fluid in the rock. See also FEP 2.2.07.11.00 for a discussion of return flow from condensation cap.

SECONDARY YMP FEP NUMBER: None
FEP NAME: None

ORIGINATOR FEP DESCRIPTION: None.

PRIMARY YMP FEP NUMBER: 2.2.08.08.00
FEP NAME: Matrix diffusion in geosphere

ORIGINATOR FEP DESCRIPTION: Matrix diffusion is the process by which nuclides and other species in the water flowing in the rock fissures migrates into the porous rock by diffusion. Matrix diffusion is a very efficient retarding mechanism, especially for strongly sorbed radionuclides due to the increase in rock surface accessible to sorption.

YMP PRIMARY FEP DESCRIPTION: Matrix diffusion is the process by which radionuclides and other species transported by advective flow in fractures or other pathways move into the matrix of the porous rock by diffusion. Matrix diffusion can be a very efficient retarding mechanism, especially for strongly sorbed radionuclides due to the increase in rock surface accessible to sorption.

SECONDARY YMP FEP NUMBER: 2.2.08.08.01
FEP NAME: Matrix diffusion (water transport)

ORIGINATOR FEP DESCRIPTION: Matrix diffusion is the process by which nuclides and other species in the water flowing in the rock fissures migrates into the porous rock by diffusion. Matrix diffusion is a very efficient retarding mechanism, especially for strongly sorbed radionuclides due to the increase in rock surface accessible to sorption.

SECONDARY YMP FEP NUMBER: 2.2.08.08.02
FEP NAME: Matrix diffusion (water transport)

ORIGINATOR FEP DESCRIPTION: Matrix diffusion is where movement of material is transverse to the direction of advection within a fracture and into the surrounding rock matrix.

SECONDARY YMP FEP NUMBER: 2.2.08.08.03
FEP NAME: Matrix diffusion (water transport)

ORIGINATOR FEP DESCRIPTION: Matrix diffusion is the process by which nuclides and other species in the water flowing in the rock fissures migrates into the porous rock by diffusion. Matrix diffusion is a very efficient retarding mechanism, especially for strongly sorbed radionuclides due to the increase in rock surface accessible to sorption.

SECONDARY YMP FEP NUMBER: 2.2.08.08.04
FEP NAME: Matrix diffusion (water transport)

ORIGINATOR FEP DESCRIPTION: Contaminants may diffuse into surrounding rock from contaminated water in a fracture zone or from contaminated rock into a nearby fracture zone, due to matrix diffusion.

SECONDARY YMP FEP NUMBER: 2.2.08.08.05
FEP NAME: Matrix diffusion (water transport)

ORIGINATOR FEP DESCRIPTION: None

SECONDARY YMP FEP NUMBER: 2.2.08.08.06
FEP NAME: Matrix diffusion (water transport)

ORIGINATOR FEP DESCRIPTION: Radionuclides can migrate from the flow porosity (i.e. open channels of small-scale water-conducting features) into the static water of pores of the adjacent wallrock by molecular diffusion. This process is known as matrix diffusion. etc.

SECONDARY YMP FEP NUMBER: 2.2.08.08.07
FEP NAME: Matrix diffusion (water transport)

ORIGINATOR FEP DESCRIPTION: Radionuclides can migrate from the flow porosity (i.e. open channels of small-scale water-conducting features) into the static water of pores of the adjacent wallrock by molecular diffusion. This process is known as matrix diffusion. etc.

SECONDARY YMP FEP NUMBER: 2.2.08.08.08
FEP NAME: Matrix diffusion (water transport)

ORIGINATOR FEP DESCRIPTION: Matrix diffusion is the process by which nuclides in the water flowing in rock fissures migrates into the porous rock by diffusion. It is governed by the characteristics of fracture fillings and the rock mass (porosity and mineralogy).

PRIMARY YMP FEP NUMBER: 2.2.08.09.00
FEP NAME: Sorption in UZ and SZ

ORIGINATOR FEP DESCRIPTION: Sorption occurs along fractures and in the matrix imbibing the carrier plume as contaminants are transported through the UZ.

YMP PRIMARY FEP DESCRIPTION: Sorption of dissolved and colloidal radionuclides can occur on the surfaces of both fractures and matrix in rock or soil along the transport path. Sorption may be reversible or irreversible, and it may occur as a linear or nonlinear process. Sorption kinetics and the availability of sites for sorption should be considered.

SECONDARY YMP FEP NUMBER: 2.2.08.09.01
FEP NAME: Far-field transport: Sorption including ion-exchange

ORIGINATOR FEP DESCRIPTION: Sorption is a general term to describe the retardation of radionuclides when they bind directly to solid surfaces.

SECONDARY YMP FEP NUMBER: 2.2.08.09.02
FEP NAME: Far-field transport: Changes in sorptive surfaces

ORIGINATOR FEP DESCRIPTION: Sorption to solid surfaces (in fractures and secondary porosity) will be controlled by the accessibility of those surfaces and their mineralogy (chemistry, structure). Over the lifetime of the repository, both the available area and the mineralogy of solid surfaces may change and, hence, the potential for sorption in the far-field will be time-dependent.

SECONDARY YMP FEP NUMBER: 2.2.08.09.03
FEP NAME: Anion-exclusion General: (in geosphere)

ORIGINATOR FEP DESCRIPTION: Mineral surfaces are usually negatively charged in contact with water. Because of the negative electric field, anions are repelled from the surface. As a consequence, the movement of anions in clays and rock matrices are restricted to the largest pores or fractures. etc.

SECONDARY YMP FEP NUMBER: 2.2.08.09.04
FEP NAME: Soil pore water pH

ORIGINATOR FEP DESCRIPTION: The pH of soil pore water is an important factor in determining the behavior and transport of contaminants in the soil because it affects sorption to soil solids. ... Decreased sorption means higher mobility and this may open up a variety of exposure pathways. etc.

SECONDARY YMP FEP NUMBER: 2.2.08.09.05
FEP NAME: Soil sorption

ORIGINATOR FEP DESCRIPTION: Soil sorption refers to the process whereby contaminants adhere to or are taken up in soil solids and become essentially immobilized. etc.

SECONDARY YMP FEP NUMBER: 2.2.08.09.06
FEP NAME: Ion exchange in soil

ORIGINATOR FEP DESCRIPTION: During ion exchange in the soil, contaminating radionuclides may become sorbed to soil materials by displacing other ions. Thus, ion exchange relates to the mobility of contaminants in soil as do other processes, such as chemical precipitation. etc.

SECONDARY YMP FEP NUMBER: 2.2.08.09.07
FEP NAME: Sorption (reversible and irreversible)

ORIGINATOR FEP DESCRIPTION: Sorption is the sticking of contaminant solutes to the surfaces of the rock by chemical interaction. It could be reversible, allowing redissolution or irreversible, removing some of the contaminant from the flow field.

SECONDARY YMP FEP NUMBER: 2.2.08.09.08
FEP NAME: Sorption - nonlinear

ORIGINATOR FEP DESCRIPTION: Some chemical elements may display nonlinear characteristics for reasons such as chemical kinetic effects, concentration effects and the formation of precipitates, etc.

SECONDARY YMP FEP NUMBER: 2.2.08.09.09
FEP NAME: Saturation (of sorption sites)

ORIGINATOR FEP DESCRIPTION: The available sorption sites may be saturated by an overabundance of contaminants or natural competing species.

SECONDARY YMP FEP NUMBER: 2.2.08.09.10
FEP NAME: Sorption (geosphere)

ORIGINATOR FEP DESCRIPTION: Sorption of contaminants will depend on factors such as the nature of the contaminant, minerals involved, mineral surface area, pH,Eh, salinity and available complexing ligands.

SECONDARY YMP FEP NUMBER: 2.2.08.09.11
FEP NAME: Sorption

ORIGINATOR FEP DESCRIPTION: None

SECONDARY YMP FEP NUMBER: 2.2.08.09.12

FEP NAME: *Sorption*

ORIGINATOR FEP DESCRIPTION: The interaction of dissolved radionuclides with rock surfaces, excluding precipitation, is termed sorption. Radionuclides can sorb on the surfaces of open channels within water-conducting features and also on the surfaces of pores accessible by matrix diffusion (i.e. pore surfaces within fracture infill and wallrock). etc.

SECONDARY YMP FEP NUMBER: *2.2.08.09.13*
FEP NAME: *Nonlinear sorption*

ORIGINATOR FEP DESCRIPTION: In general, the partitioning of radionuclides between sorbed and aqueous phases is dependent on elemental concentration (i.e. the concentration of the element of which the radionuclide under consideration is an isotope). Where such dependency exists, sorption is said to be nonlinear.

SECONDARY YMP FEP NUMBER: *2.2.08.09.14*
FEP NAME: *Nonlinear sorption*

ORIGINATOR FEP DESCRIPTION: The interaction of dissolved radionuclides with rock surfaces, excluding precipitation, is termed sorption. Radionuclides can sorb on the surfaces of open channels within water-conducting features and also on the surfaces of pores accessible by matrix diffusion (i.e. pore surfaces within fracture infill and wallrock). etc.

SECONDARY YMP FEP NUMBER: *2.2.08.09.15*
FEP NAME: *Nonlinear sorption*

ORIGINATOR FEP DESCRIPTION: In general, the partitioning of radionuclides between sorbed and aqueous phase is dependent on elemental concentration (i.e. the concentration of the element of which the radionuclide under consideration is an isotope). Where such dependency exists, sorption is said to be nonlinear. etc.

SECONDARY YMP FEP NUMBER: *2.2.08.09.16*
FEP NAME: *Sorption*

ORIGINATOR FEP DESCRIPTION: The interaction of dissolved radionuclides with rock surfaces, excluding precipitation, is termed sorption. Sorption would retard the migration of radionuclides through the HPD. The degree to which radionuclides sorb on pore surfaces is dependent on the elemental concentration(...) and on the properties of the rock-water system under consideration-in particular, the mineralogy and the groundwater chemistry.

SECONDARY YMP FEP NUMBER: *2.2.08.09.17*
FEP NAME: *Radionuclide sorption*

ORIGINATOR FEP DESCRIPTION: The physio-chemical interaction of dissolved radionuclides with soils and sediments is termed sorption. This interaction is affected by chemical, physical and biological conditions. For biosphere modeling purposes, reversible equilibrium sorption is assumed. Concentration independent (linear) sorption is quantified by K_d values, the evaluation of which takes account of the particular environmental media.

SECONDARY YMP FEP NUMBER: *2.2.08.09.18*
FEP NAME: *Sorption*

ORIGINATOR FEP DESCRIPTION: Sorption is the collective term for adsorption of particles (molecules, ions, colloids) on outer or inner surfaces of solids. The forces responsible for sorption range from "physical" interactions (van der Waals' forces) to the formation of chemical bonds. ... Sorption will affect the transport and release of sorbing radionuclides from the different repository barriers.

SECONDARY YMP FEP NUMBER: *2.2.08.09.19*
FEP NAME: *Actinide sorption*

ORIGINATOR FEP DESCRIPTION: Sorption may be defined as the accumulation of matter at the interface between a solid and an aqueous solution. Within performance assessment calculations, including those made for the WIPP, the use of isotherm representations of actinide sorption prevails because of their computational simplicity in comparison with other models.

SECONDARY YMP FEP NUMBER: 2.2.08.09.20
FEP NAME: Kinetics of sorption

ORIGINATOR FEP DESCRIPTION: The relevance to the WIPP of sorption reaction kinetics lies in their effects on chemical transport. Sorption of waste contaminants to static surfaces of the disposal system such as seals and host rocks acts to retard chemical transport. Sorption of waste contaminants to potentially mobile surfaces, such as colloids, however, may act to enhance chemical transport, particularly if the kinetics of contaminant desorption are slow or the process is irreversible (non-equilibrium). ... The potential effects of reaction kinetics in adsorption processes in the Culebra are encompassed in the range of K_ds used.

SECONDARY YMP FEP NUMBER: 2.2.08.09.21
FEP NAME: Changes in sorptive surfaces

ORIGINATOR FEP DESCRIPTION: The geochemical speciation of the Culebra groundwaters and the effects of changes in sorptive surfaces are implicitly accounted for in performance assessment calculations for the WIPP in the ranges of K_ds used.

SECONDARY YMP FEP NUMBER: 2.2.08.09.22
FEP NAME: Sorption - nonlinear (geosphere)

ORIGINATOR FEP DESCRIPTION: Sorption of contaminants may show a nonlinear dependence on factors such as contaminant concentration. The extent of sorption along a flow path may also change in response to different combinations of minerals and groundwater chemistry.

PRIMARY YMP FEP NUMBER: 2.2.08.10.00
FEP NAME: Colloidal transport in geosphere

ORIGINATOR FEP DESCRIPTION: Radionuclide transport may be enhanced by organic and inorganic colloids in the far-field, when poorly soluble radionuclides sorb onto the colloids and are subsequently transported by advection along fractures. Colloids may form in the far-field or may migrate into the far-field or the biosphere.

YMP PRIMARY FEP DESCRIPTION: Radionuclides may be transported in groundwater in the geosphere as colloidal species. Types of colloids include true colloids, pseudocolloids, and microbial colloids.

SECONDARY YMP FEP NUMBER: 2.2.08.10.01
FEP NAME: Far-field transport: Transport of radionuclides bound to microbes

ORIGINATOR FEP DESCRIPTION: Microbes can be considered as colloids, as they are similar in size and radionuclides may sorb to them and be advectively transported along fractures in the same manner as colloids. Microbes may, however, through biological processes, enhance the transport of radionuclides through the far-field over and above that expected for colloids.

SECONDARY YMP FEP NUMBER: 2.2.08.10.02
FEP NAME: Colloid transport occurs in a carrier plume (in geosphere)

ORIGINATOR FEP DESCRIPTION: Radionuclides are dissolved into the carrier plume.

SECONDARY YMP FEP NUMBER: 2.2.08.10.03
FEP NAME: Colloids (in geosphere)

ORIGINATOR FEP DESCRIPTION: Colloids may be formed in the EDZ by erosion of the bentonite or precipitation of major elements(e.g. silica) or radionuclides due to lower solubility in the EDZ than in bentonite porewater.

PRIMARY YMP FEP NUMBER: 2.2.10.03.00
FEP NAME: Natural geothermal effects

ORIGINATOR FEP DESCRIPTION: There can be natural geothermal flows due for example to variations in thermal conductivity. Also thermally induced flows can be induced by heat output from the repository.

YMP PRIMARY FEP DESCRIPTION: The existing geothermal gradient, and spatial or temporal variability in that gradient, may affect groundwater flow in the unsaturated and saturated zones.

SECONDARY YMP FEP NUMBER: 2.2.10.03.01
FEP NAME: Natural thermal effects (in geosphere)
ORIGINATOR FEP DESCRIPTION: None

SECONDARY YMP FEP NUMBER: 2.2.10.03.02
FEP NAME: Geothermal regime

ORIGINATOR FEP DESCRIPTION: The temperature field within the crystalline basement is determined by (i) the large scale geological and petrophysical properties of the rock (e.g. radiogenic heat production, thermal conductivity) and (ii) by the hydrogeological properties of the rock (in particular, the hydraulic conductivity), etc. ... Temperature gradients may drive groundwater flow; this is neglected in groundwater flow modeling for Kristallin-I.

SECONDARY YMP FEP NUMBER: 2.2.10.03.03
FEP NAME: Geothermal regime

ORIGINATOR FEP DESCRIPTION: The temperature field within the crystalline basement is determined by (i) the large scale geological and petrophysical properties of the rock (e.g. radiogenic heat production, thermal conductivity) and (ii) by the hydrogeological properties of the rock (in particular, the hydraulic conductivity), etc. ... Temperature gradients may drive groundwater flow; this is neglected in groundwater flow modeling for Kristallin-I.

SECONDARY YMP FEP NUMBER: 2.2.10.03.04
FEP NAME: Geothermal gradient effects

ORIGINATOR FEP DESCRIPTION: Groundwater flow will be influenced by existing geothermal gradients; groundwater may tend to form convection cells.

PRIMARY YMP FEP NUMBER: 2.2.10.10.00
FEP NAME: Two-phase bouyant flow / heat pipes

ORIGINATOR FEP DESCRIPTION: Heat from waste generates 2-phase buoyant flow. The vapor phase (water vapor) escapes from the mountain.

YMP PRIMARY FEP DESCRIPTION: Heat from waste generates two-phase buoyant flow. The vapor phase (water vapor) escapes from the mountain. A heat pipe consists a system for transferring energy between a hot and a cold region(source and sink respectively) using the heat of vaporization and movement of the vapor as the transfer mechanism. Two-phase circulation continues until the heat source is too weak to provide thermal gradients required to drive it. Any alteration of the rock adjacent to the drift produces may include dissolution which maintains the permeability necessary to support the circulation (as inferred for some geothermal systems).

SECONDARY YMP FEP NUMBER: 2.2.10.10.01
FEP NAME: Heat pipe -evolving

ORIGINATOR FEP DESCRIPTION: A heat pipe evolves by altering the rock adjacent to the drift producing local dry-out, shutting off circulation and migrating further into the rock.

SECONDARY YMP FEP NUMBER: 2.2.10.10.02
FEP NAME: Heat pipe -continuing

ORIGINATOR FEP DESCRIPTION: A heat pipe is "continuing" when the 2-phase circulation continues until the heat source is too weak to provide thermal gradients required to drive it.

SECONDARY YMP FEP NUMBER: 2.2.10.10.03
FEP NAME: Heat pipe formation, 2-phase system

ORIGINATOR FEP DESCRIPTION: A heat pipe consists a system for transferring energy between a hot and a cold region(source and sink respectively) using the heat of vaporization and movement of the vapor as the transfer mechanism.

PRIMARY YMP FEP NUMBER: 2.3.01.00.00
FEP NAME: Topography and morphology

ORIGINATOR FEP DESCRIPTION: Topography and morphology refers to FEPs related to a the relief and shape of the surface environment and its evolution.

YMP PRIMARY FEP DESCRIPTION: This category includes FEPs related to the topography and surface morphology of the disposal region. Topographical features include outcrops and hills, water-filled depressions, wetlands, recharge areas and discharge areas. Topography, precipitation, and surficial permeability distribution in the system will determine the flow boundary conditions, i.e. location and amount of recharge and discharge in the system.

SECONDARY YMP FEP NUMBER: 2.3.01.00.01
FEP NAME: Topography (current)

ORIGINATOR FEP DESCRIPTION: Present-day topographical features should be modeled, including outcrops and hills, water-filled depressions, wetlands, recharge areas and discharge areas.

SECONDARY YMP FEP NUMBER: 2.3.01.00.02
FEP NAME: Topography (future)

ORIGINATOR FEP DESCRIPTION: Changes affecting topographical features should be modeled or estimated, so that subsequent effects on flow can be taken into account.

SECONDARY YMP FEP NUMBER: 2.3.01.00.03
FEP NAME: Terrestrial surface

ORIGINATOR FEP DESCRIPTION: Land areas on the Shield include rocky outcrops, bare soil, grassland, bush and forest. Each of these types of areas has unique physical, chemical and biological properties that may influence the behavior and transport of contaminants.

SECONDARY YMP FEP NUMBER: 2.3.01.00.04
FEP NAME: Physiography

ORIGINATOR FEP DESCRIPTION: The DOE addresses issues related to groundwater flow and radionuclide transport within the context of a conceptual model of how the natural hydrologic system works on a large scale. etc.

SECONDARY YMP FEP NUMBER: 2.3.01.00.05
FEP NAME: Geomorphological (processes)

ORIGINATOR FEP DESCRIPTION: None
SECONDARY YMP FEP NUMBER: 2.3.01.00.06
FEP NAME: External flow boundaries (surface environment)

ORIGINATOR FEP DESCRIPTION: Topography, climate precipitation and surficial permeability distribution in the system will determine the flow boundary conditions, i.e. location and amount of recharge and discharge in the system.

SECONDARY YMP FEP NUMBER: 2.3.01.00.07
FEP NAME: Changes in geometry and driving forces of the flow system

ORIGINATOR FEP DESCRIPTION: The geometry of the groundwater flow-field in the region around a repository will be bounded by a variety of physical features, e.g. topographic highs or faults. Over the lifetime of the repository the flow-field geometry and the driving forces for flow will change as the physical boundaries are altered by processes such as glaciation, erosion or sea level change. etc.

PRIMARY YMP FEP NUMBER: 2.3.11.01.00
FEP NAME: Precipitation

ORIGINATOR FEP DESCRIPTION: The amount of precipitation depends on climate and transports solutes with it as it flows downward through the soil profile or escapes as runoff.

YMP PRIMARY FEP DESCRIPTION: Precipitation is an important control on the amount of recharge. It transports solutes with it as it flows downward through the subsurface or escapes as runoff. The amount of precipitation depends on climate.

SECONDARY YMP FEP NUMBER: 2.3.11.01.01
FEP NAME: Precipitation, temperature and soil water balance

ORIGINATOR FEP DESCRIPTION: None

SECONDARY YMP FEP NUMBER: 2.3.11.01.02
FEP NAME: Flood (meteorology)

ORIGINATOR FEP DESCRIPTION: The current levels of meteoric precipitation could change substantially, leading to much greater flows of water through the geosphere, with accompanying changes to the biosphere.

SECONDARY YMP FEP NUMBER: 2.3.11.01.03
FEP NAME: Extremes of precipitation, snow melt and associated flooding (meteorology)

ORIGINATOR FEP DESCRIPTION: None

SECONDARY YMP FEP NUMBER: 2.3.11.01.04
FEP NAME: Precipitation (meteorology)

ORIGINATOR FEP DESCRIPTION: Precipitation in the region of the WIPP is low (about 13 inches per year). Precipitation is an important control on the amount of recharge that reaches the groundwater system and is accounted for in performance assessment calculations by use of a sampled parameter for scaling flow in the Culebra.

PRIMARY YMP FEP NUMBER: 2.3.11.02.00
FEP NAME: Surface runoff and flooding

ORIGINATOR FEP DESCRIPTION: Precipitation which does not infiltrate the soil, but moves across the surface directly into a surface water body, e.g. river, is called surface runoff. It may be an important cause of erosion.

YMP PRIMARY FEP DESCRIPTION: Surface runoff and evapotranspiration are components in the water balance, together with precipitation and infiltration. They can also be important vehicles for the dispersion of contaminants. Surface runoff produces erosion, and can feed washes, arroyos, and impoundments, where flooding may lead to increased recharge.

SECONDARY YMP FEP NUMBER: 2.3.11.02.01
FEP NAME: Runoff (near surface hydrology)

ORIGINATOR FEP DESCRIPTION: Runoff refers to precipitation water that runs off laterally, at or below the surface, to drain into a water body. Thus, runoff is important in determining the flushing rate of surface water bodies (Bird et al. 1994). Runoff may also carry contaminants, scavenged from the atmosphere or leached from the soil, to water bodies. Runoff is therefore an important vehicle for the dispersion of contaminants. Moreover, runoff is an important component in the water balance which, together with precipitation, infiltration and evapotranspiration, determines irrigation water needs for optimal crop production.

SECONDARY YMP FEP NUMBER: 2.3.11.02.02
FEP NAME: Flooding (near surface hydrology)

ORIGINATOR FEP DESCRIPTION: Short-term flooding can alter the landscape and may destroy, or help create, agricultural land. Flooding could be caused by intentional or accidental human actions. There could also be natural causes of flooding such as beavers. etc.

SECONDARY YMP FEP NUMBER: 2.3.11.02.03
FEP NAME: Evapotranspiration (near surface hydrology)

ORIGINATOR FEP DESCRIPTION: Evapotranspiration depends on the climate and causes solutes to move upwards in the soil layers; even when the annual precipitation(P) is larger than the Evapotranspiration(ETP), ETP may still exceed P during part of the year etc.

SECONDARY YMP FEP NUMBER: 2.3.11.02.04
FEP NAME: Flooding occurs in Drill Hole Wash and increases percolation below the wash

ORIGINATOR FEP DESCRIPTION: Flooding occurs in Drill Hole Wash, and percolation flux is substantially increased below the wash. Some water seeps to sealed shafts and boreholes where there are unexpectedly large flows down through the seal material or down through the disturbed rock around the seals.

SECONDARY YMP FEP NUMBER: 2.3.11.02.05
FEP NAME: Faulting at the surface produces a scarp causing an impoundment

ORIGINATOR FEP DESCRIPTION: Faulting produces a scarp at the surface which forms an impoundment during periods of high precipitation. Percolation flux is substantially increased below the impoundment.

SECONDARY YMP FEP NUMBER: 2.3.11.02.06
FEP NAME: River flooding

ORIGINATOR FEP DESCRIPTION: Changes in the surface environment driven by natural climate change are expected to occur over the next 10,000 tears. Intermittent flooding of stream channels and the formation of shallow lakes will occur in the WIPP region over the next 10,000 years. etc.

PRIMARY YMP FEP NUMBER: 3.1.01.01.00
FEP NAME: Radioactive decay and ingrowth

ORIGINATOR FEP DESCRIPTION: Calculation of the radioactive decay of radionuclides and the growth of daughter products as a consequence of that decay. The repository inventory defines initial quantities of radionuclides and standard decay chain theory and half-lives are used to calculate the radionuclide quantities at any later time.

YMP PRIMARY FEP DESCRIPTION: Radioactive decay of the fuel in the repository changes the radionuclide content in the fuel with time and generates heat. Radionuclide quantities in the system at any time are the result of the radioactive decay and the growth of daughter products as a consequence of that decay. The type of radiation generated by the decay depends on the radionuclide, and the penetrating distance of the radiation depends on the type of radiation, its energy and the surrounding medium.

SECONDARY YMP FEP NUMBER: 3.1.01.01.01
FEP NAME: Radioactive decay

ORIGINATOR FEP DESCRIPTION: Radioactive decay, including the ingrowth of progeny in decay chains, will affect concentrations of radionuclides and stable isotopes in the waste matrices, and in other parts of the vault.

SECONDARY YMP FEP NUMBER: 3.1.01.01.02
FEP NAME: Radioactive decay

ORIGINATOR FEP DESCRIPTION: Radioactive decay, including the ingrowth of progeny, will affect the movement and concentrations of contaminants. Members of a radioactive decay chain may have different sorption and transport properties in the geosphere.

SECONDARY YMP FEP NUMBER: 3.1.01.01.03
FEP NAME: Radioactive decay

ORIGINATOR FEP DESCRIPTION: Radionuclides decay and are transformed into other radionuclides or stable isotopes, with characteristic half-lives that can range from fractions of seconds to millions of years. During decay, various types of radiation are emitted that can be harmful to all organisms. etc.

SECONDARY YMP FEP NUMBER: 3.1.01.01.04
FEP NAME: Radioactive decay and ingrowth

ORIGINATOR FEP DESCRIPTION: None

SECONDARY YMP FEP NUMBER: 3.1.01.01.05
FEP NAME: Radioactive decay

ORIGINATOR FEP DESCRIPTION: Radionuclides decay to form products (stable or radioactive) at characteristic rates. Decay schemes and half-lives are relatively well established but there may be some variation in exact data used between different models. etc.

SECONDARY YMP FEP NUMBER: 3.1.01.01.06
FEP NAME: Radioactive decay

ORIGINATOR FEP DESCRIPTION: The radioactive decay of the fuel in the repository is well known. It changes the initial radionuclide content in the fuel with time and generates heat. The type of radiation generated by the decay depends on the radionuclide, and the penetrating distance of the radiation depends on the type of radiation, its energy and the surrounding medium.

SECONDARY YMP FEP NUMBER: 3.1.01.01.07
FEP NAME: Radioactive decay of mobile nuclides

ORIGINATOR FEP DESCRIPTION: Refers to radionuclides which are released from the fuel and are dissolved in the water or sorbed or reprecipitated in barriers outside the fuel. These radionuclides will decay thereby changing the concentration and distribution in the water and in the barrier materials.

SECONDARY YMP FEP NUMBER: 3.1.01.01.08
FEP NAME: Radionuclide decay and ingrowth

ORIGINATOR FEP DESCRIPTION: The PA code, NUTS, calculates the overall movement and decay of radionuclides in the repository and disposal system. etc.

SECONDARY YMP FEP NUMBER: 3.1.01.01.09
FEP NAME: Radiological events and processes

ORIGINATOR FEP DESCRIPTION: None

ATTACHMENT II

BOREHOLES AND REPOSITORY SEALS FEPS DESCRIPTIONS

PRIMARY YMP FEP NUMBER: 1.1.01.01.00

FEP NAME: Open site investigation boreholes

ORIGINATOR FEP DESCRIPTION: Boreholes that have been left open, improperly sealed or reopened for some reason, could modify flow and transport properties, including transport within the borehole and within the damaged zone surrounding the borehole. Similar effects could occur for the vaults.

YMP PRIMARY FEP DESCRIPTION: Site investigation boreholes that have been left open, improperly sealed, or reopened for some reason, could modify flow and transport properties and produce enhanced pathways between the surface and the repository.

SECONDARY YMP FEP NUMBER: 1.1.01.01.01

FEP NAME: Exploratory boreholes (sealing)

ORIGINATOR FEP DESCRIPTION: Exploratory boreholes may remain open for a time for monitoring purposes but are expected to be sealed eventually. Their relatively small diameters and sparse occurrence will mean that they are unlikely to have any long-term safety implications.

SECONDARY YMP FEP NUMBER: 1.1.01.01.02

FEP NAME: Investigation boreholes

ORIGINATOR FEP DESCRIPTION: There are a large number of boreholes drilled from the surface as part of the site investigation program for WIPP. ... There are four WIPP investigation boreholes, however, that do intersect the repository horizon within the controlled area. These could potentially act as pathways to the Culebra or to the surface for radionuclides that migrate along the anhydrite layers a and b, MB138, and MB139.

SECONDARY YMP FEP NUMBER: 1.1.01.01.03

FEP NAME: Underground boreholes

ORIGINATOR FEP DESCRIPTION: The site investigation program has involved the drilling of boreholes from within the excavated part of the repository. Following their use for monitoring or other purposes, these underground boreholes will be sealed where practical, and salt creep will also serve to consolidate the seal and close the boreholes.

PRIMARY YMP FEP NUMBER: 1.1.01.02.00

FEP NAME: Loss of integrity of borehole seals

ORIGINATOR FEP DESCRIPTION: A number of boreholes drilled from the surface in and around the repository footprint during the exploration and site chacterisation phase. These boreholes will be sealed after use. If the seals degrade the boreholes may offer a short-circuit route to the biosphere.

YMP PRIMARY FEP DESCRIPTION: Degradation and/or failure of seals in site investigation boreholes could alter the flow path between the surface and the repository and possibly create a short-circuit to the biosphere.

SECONDARY YMP FEP NUMBER: 1.1.01.02.01

FEP NAME: Investigation borehole seal failure and degradation

ORIGINATOR FEP DESCRIPTION: None.

SECONDARY YMP FEP NUMBER: 1.1.01.02.02

FEP NAME: Borehole seal failure

ORIGINATOR FEP DESCRIPTION: Failure of the borehole seals and grouts could modify flow and transport properties, including transport within the borehole and between the rocks and seals.

PRIMARY YMP FEP NUMBER: 1.1.02.01.00

FEP NAME: Site flooding (during construction and operation)

ORIGINATOR FEP DESCRIPTION: None.

YMP PRIMARY FEP DESCRIPTION: Flooding of the site during operations could introduce water into the underground, and could affect long-term performance.

SECONDARY YMP FEP NUMBER: 1.1.02.01.01
FEP NAME: Repository flooding during operation

ORIGINATOR FEP DESCRIPTION: None.

PRIMARY YMP FEP NUMBER: 1.1.04.01.00
FEP NAME: Incomplete closure

ORIGINATOR FEP DESCRIPTION: Incomplete or improper closure of the repository could lead to enhanced radionuclide releases to the geosphere and biosphere. Inadequate closure could result from failures in the repository seals or from abandonment of the repository.

YMP PRIMARY FEP DESCRIPTION: Disintegration of society could result in incomplete closure, sealing and decommissioning of the disposal vault.

SECONDARY YMP FEP NUMBER: 1.1.04.01.01
FEP NAME: Vault closure (geosphere)

ORIGINATOR FEP DESCRIPTION: Incomplete or improper closure of the vault could lead to significant changes to anticipated flow in the geosphere.

SECONDARY YMP FEP NUMBER: 1.1.04.01.02
FEP NAME: Non-sealed repository

ORIGINATOR FEP DESCRIPTION: Open or partially open boreholes and shafts will enhance disruption of the mechanical barriers, increase the groundwater flow and produce paths from the repository with practically no sorption or matrix diffusion.

SECONDARY YMP FEP NUMBER: 1.1.04.01.03
FEP NAME: Poor closure

ORIGINATOR FEP DESCRIPTION: None.

SECONDARY YMP FEP NUMBER: 1.1.04.01.04
FEP NAME: Abandonment of unsealed repository

ORIGINATOR FEP DESCRIPTION: None.

SECONDARY YMP FEP NUMBER: 1.1.04.01.05
FEP NAME: Unsealed boreholes and/or shafts

ORIGINATOR FEP DESCRIPTION: This is a variant of FEP J5.02 (non-sealed repository), even if a non-sealed repository may include more than unsealed boreholes and shafts. Unsealed boreholes and shafts affect the stability of the technical barriers, the transport in the nearby rock and transport in the geosphere.

SECONDARY YMP FEP NUMBER: 1.1.04.01.06
FEP NAME: Operation and closure

ORIGINATOR FEP DESCRIPTION: None.

PRIMARY YMP FEP NUMBER: 1.1.11.00.00

FEP NAME: Monitoring of repository

ORIGINATOR FEP DESCRIPTION: Monitoring of repository refers to FEPs related to any monitoring that is carried out during operations or following closure of sections of, or the total, repository. This includes monitoring for operational safety and also monitoring of parameters related to the long-term safety and performance.

YMP PRIMARY FEP DESCRIPTION: This category contains FEPs related to monitoring that is carried out during or after operations, for either operational safety or verification of long-term performance. Monitoring boreholes could provide enhanced pathways between the surface and the repository.

SECONDARY YMP FEP NUMBER: 1.1.11.00.01
FEP NAME: Monitoring and remedial activities

ORIGINATOR FEP DESCRIPTION: Boreholes used to monitor performance could provide pathways for contaminant transport. Similarly some activities to remedy problems could lead to enhanced transport.

SECONDARY YMP FEP NUMBER: 1.1.11.00.02
FEP NAME: Postclosure monitoring

ORIGINATOR FEP DESCRIPTION: Postclosure monitoring schemes must be designed with care. A monitoring well represents a short path to the biosphere and may also be used for a water supply. etc.

SECONDARY YMP FEP NUMBER: 1.1.11.00.03
FEP NAME: Post-closure monitoring

ORIGINATOR FEP DESCRIPTION: None.

SECONDARY YMP FEP NUMBER: 1.1.11.00.04
FEP NAME: Postclosure monitoring

ORIGINATOR FEP DESCRIPTION: Monitoring methods may be detrimental to the performance of the disposal system. Postclosure monitoring is required by 40 CFR 191.14(b) as an assurance requirement to "detect substantial and detrimental deviations from performance". etc.

PRIMARY YMP FEP NUMBER: 1.4.04.02.00
FEP NAME: Abandoned and undetected boreholes

ORIGINATOR FEP DESCRIPTION: Future or existing boreholes affect performance.

YMP PRIMARY FEP DESCRIPTION: Abandoned and undetected boreholes could provide pathways for preferential flow and, potentially, contaminant transport between any intersected zones. These flow connections could also result in geochemical changes in the receiving hydrologic units.

SECONDARY YMP FEP NUMBER: 1.4.04.02.01
FEP NAME: Exploratory borehole creates flow pathway

ORIGINATOR FEP DESCRIPTION: An exploratory borehole creates a pathway for preferential flow through the upper nonwelded unit, and a wetter zone develops beneath in the Topopah Spring welded unit.

SECONDARY YMP FEP NUMBER: 1.4.04.02.02
FEP NAME: Container lies in the trace of an old borehole

ORIGINATOR FEP DESCRIPTION: A horizontally-emplaced canister lies in the trace of an old borehole, which is a preferential path for water. Corrosion and transport are accelerated.

SECONDARY YMP FEP NUMBER: 1.4.04.02.03
FEP NAME: Waste-induced borehole flow (in waste and EBS)

ORIGINATOR FEP DESCRIPTION: ... Abandoned boreholes could provide pathways for fluid flow and, potentially, contaminant transport between any intersected zones. For example, such boreholes could provide pathways for vertical flow between transmissive units in the Rustler, or between the Culebra and units below the Salado, which could affect fluid densities, flow rates, and flow directions. The exact mechanism by which waste contributes appears to be by being sequestered in waste panels which could function as pressure sinks and sources.

SECONDARY YMP FEP NUMBER: 1.4.04.02.04
FEP NAME: Flow through undetected boreholes

ORIGINATOR FEP DESCRIPTION: Abandoned water, potash, oil, and gas exploration and production boreholes exist within and outside the controlled area. The DOE assumes that records of past and present drilling activities in New Mexico are accurate and that evidence of any preexisting boreholes would be included in these records.

SECONDARY YMP FEP NUMBER: 1.4.04.02.05
FEP NAME: Natural borehole fluid flow

ORIGINATOR FEP DESCRIPTION: ... Abandoned boreholes could provide pathways for fluid flow and, potentially, contaminant transport between any intersected zones. For, example, such boreholes could provide pathways for vertical flow between transmissive units in the Rustler, or between the Culebra and units below the Salado, which could affect fluid densities, flow rates, and flow directions.

SECONDARY YMP FEP NUMBER: 1.4.04.02.06
FEP NAME: Borehole-induced mineralization

ORIGINATOR FEP DESCRIPTION: ... Fluid flow between hydraulically conductive horizons through a borehole may result in changes in permeability in the effected units through mineral precipitation. For example: Limited calcite precipitation may occur as the brines mix in the Culebra immediately surrounding the borehole, and calcite dissolution may occur as the brines migrate away from the borehole due to variations in water chemistry along the flow path.

SECONDARY YMP FEP NUMBER: 1.4.04.02.07
FEP NAME: Borehole-induced geochemical changes

ORIGINATOR FEP DESCRIPTION: Movement of fluids through abandoned boreholes could result in borehole-induced geochemical changes in the receiving units such as the Salado interbeds or Culebra. Such geochemical changes could alter radionuclide migration rates within the disposal system in the affected units if they occur sufficiently close to the edge of the controlled area, or if they occur as a result of flow through existing boreholes within the controlled area through their effects on colloid transport and sorption.

PRIMARY YMP FEP NUMBER: 2.1.05.01.00
FEP NAME: Seal physical properties

ORIGINATOR FEP DESCRIPTION: Physical properties are specified for the five materials that will be used in the shaft seal system: clay, salt, concrete, asphalt, and earthen fill. The permeability of concrete is assumed to increase after 400 years due to degradation. etc.

YMP PRIMARY FEP DESCRIPTION: Physical properties of the seals emplaced in the access ramps, ventilation shafts, and exploratory boreholes may affect the long-term performance of the disposal system. These properties include the location of the seals (and the openings they seal), and the physical and chemical characteristics of the sealing materials.

SECONDARY YMP FEP NUMBER: 2.1.05.01.01
FEP NAME: Seal geometry

ORIGINATOR FEP DESCRIPTION: The four shafts connecting the WIPP repository to the surface are represented in performance assessment with a single shaft with a cross section and volume equal to the total cross section and volume of the four real shafts it represents. etc.

SECONDARY YMP FEP NUMBER: 2.1.05.01.02
FEP NAME: Consolidation of seals

ORIGINATOR FEP DESCRIPTION: The conceptual model for the shafts and shaft seals used in performance assessment has been chosen to provide a reasonable and realistic basis for simulating long-term fluid flow through the shaft seal system and to allow evaluation of the effect that uncertainty about long-term properties of the shaft seal system may have on cumulative radionuclide releases from the disposal system.

SECONDARY YMP FEP NUMBER: 2.1.05.01.03
FEP NAME Shaft and tunnel seals

ORIGINATOR FEP DESCRIPTION: At closure, massive concrete tunnel seals and bentonite-concrete rock grouting will be emplaced to hydraulically isolate the individual HLW panels and TRU silos from each other and from higher permeability zones in the host rock. Similar seals will be emplaced in the shafts and investigation boreholes.

PRIMARY YMP FEP NUMBER: 2.1.05.02.00
FEP NAME: Groundwater flow and radionuclide transport in seals

ORIGINATOR FEP DESCRIPTION: Localized percolation driven by temperature gradients could lead to early failure of seals and grouts, and the formation of new significant flow pathways, within the vault and shafts leading to the vault.

YMP PRIMARY FEP DESCRIPTION: Groundwater flow in through seals in the access ramps, ventilation shafts, and exploratory boreholes could affect long-term performance of the disposal system. Radionuclide transport through borehole seals below the repository should be considered.

SECONDARY YMP FEP NUMBER: None
FEP NAME: None

ORIGINATOR FEP DESCRIPTION: None

PRIMARY YMP FEP NUMBER: 2.1.05.03.00
FEP NAME: Seal degradation

ORIGINATOR FEP DESCRIPTION: Failure of the shaft seals and grouts could modify flow and transport properties, including enhanced transport within the shafts (possibly with percolation) and between the seals and rock.

YMP PRIMARY FEP DESCRIPTION: Degradation of seals in the access ramps, ventilation shafts, and exploratory boreholes could modify flow and transport properties, including enhanced flow and transport between the surface and the repository . Possible mechanisms for seal degradation include: chemical alteration from water interactions, wetting associated with condensation, and thermally -induced stress-strain changes.

SECONDARY YMP FEP NUMBER: 2.1.05.03.01
FEP NAME: Seal evolution

ORIGINATOR FEP DESCRIPTION: The properties of the seals and grouts could evolve in time, due to processes such as silica cementation, alteration or dissolution of seal and grout materials.

SECONDARY YMP FEP NUMBER: 2.1.05.03.02
FEP NAME: Seal failure

ORIGINATOR FEP DESCRIPTION: Chemical or physical processes may cause early or accelerated failure of the seals and grouts. This would lead to changed water flow patterns and transport pathways to and from the vault.

SECONDARY YMP FEP NUMBER: 2.1.05.03.03
FEP NAME: Degradation of hole and shaft seals

ORIGINATOR FEP DESCRIPTION: In this context, degradation is a physical or chemical process leading to reduced or completely lost sealing capacity.

SECONDARY YMP FEP NUMBER: 2.1.05.03.04
FEP NAME: Shaft or access tunnel seal failure and degradation

ORIGINATOR FEP DESCRIPTION: None.

SECONDARY YMP FEP NUMBER: 2.1.05.03.05
FEP NAME: Degradation of hole and shaft seals

ORIGINATOR FEP DESCRIPTION: Considers the degradation of the material used to seal investigation boreholes and access shafts in the repository. In this context degradation is a physical or chemical process leading to reduced or completely lost sealing of boreholes and access shafts. etc.

SECONDARY YMP FEP NUMBER: 2.1.05.03.06
FEP NAME: Loss of integrity of shaft or access tunnel seals

ORIGINATOR FEP DESCRIPTION: Access to the repository during the operational phase will be via two parallel long (two kilometers) spiral tunnel from the surface which are likely to be lined with concrete. ... The access tunnels and ventilation shafts will be backfilled and sealed at closure. If the seals fail, the tunnel and shafts will provide short-circuit pathways to the surface.

SECONDARY YMP FEP NUMBER: 2.1.05.03.07
FEP NAME: Mechanical degradation of seals

ORIGINATOR FEP DESCRIPTION: ... Shaft seal materials have been selected in part because of their exceptional durability. ... Concrete has been shown to degrade under certain conditions, and clays can be more transmissive to brine than potable water. etc.

SECONDARY YMP FEP NUMBER: 2.1.05.03.08
FEP NAME: Chemical degradation of seals

ORIGINATOR FEP DESCRIPTION: The conceptual model for the shafts and shaft seals used in the performance assessment has been chosen to provide a reasonable and realistic basis for simulating long-term fluid flow through the shaft seal system and to allow evaluation of the effect that uncertainty about the long-term properties of the shaft seal system may have on cumulative radionuclide releases from the disposal system.

ATTACHMENT III

EXTREME CLIMATE / EPISODIC TRANSIENT FLOW FEPS DESCRIPTIONS

PRIMARY YMP FEP NUMBER: 1.3.04.00.00
FEP NAME: Periglacial effects

ORIGINATOR FEP DESCRIPTION: Periglacial effects refers to FEPs related to the physical processes and associated landforms in cold but ice-sheet-free environments.

YMP PRIMARY FEP DESCRIPTION: This category category contains FEPs related to the physical processes and associated landforms in cold but ice-sheet-free environments. Permafrost and seasonal freeze/thaw cycles are characteristic of periglacial environments.

SECONDARY YMP FEP NUMBER: 1.3.04.00.01
FEP NAME: Permafrost

ORIGINATOR FEP DESCRIPTION: There are lot of evidences that Sweden has gone through several cycles of permafrost during the quaternary period (last 2 Myr.). At present, in the Spitzbergen area, the permafrost depth is 450 m, and in Siberia, depths exceeding 1500 m have been reported.

SECONDARY YMP FEP NUMBER: 1.3.04.00.02
FEP NAME: Accumulation of gases under permafrost

ORIGINATOR FEP DESCRIPTION: Gases from deeper geological layers might accumulate in the repository during permafrost, especially during the early phase when the nearby rock is still kept at higher temperatures.

SECONDARY YMP FEP NUMBER: 1.3.04.00.03
FEP NAME: Periglacial effects

ORIGINATOR FEP DESCRIPTION: None.

SECONDARY YMP FEP NUMBER: 1.3.04.00.04
FEP NAME: Frost weathering

ORIGINATOR FEP DESCRIPTION: None.

SECONDARY YMP FEP NUMBER: 1.3.04.00.05
FEP NAME: Solifluction

ORIGINATOR FEP DESCRIPTION: None.

SECONDARY YMP FEP NUMBER: 1.3.04.00.06
FEP NAME: Tundra climate

ORIGINATOR FEP DESCRIPTION: A tundra climate is characterized by low mean annual temperatures which result in a short growing season. etc. [The point is that development of such a climate is possible in northern Switzerland during the performance period of a repository].

SECONDARY YMP FEP NUMBER: 1.3.04.00.07
FEP NAME: Permafrost

ORIGINATOR FEP DESCRIPTION: As the climate cools, air temperature will fall substantially below freezing much of the year. If these conditions are sustained, then permafrost (permanently frozen ground) may develop. etc.

SECONDARY YMP FEP NUMBER: 1.3.04.00.08
FEP NAME: Permafrost

ORIGINATOR FEP DESCRIPTION: There is evidence that Sweden has gone through several cycles for permafrost during the Quaternary period (last 2 m y.) At present, in the Spitzbergen area, the permafrost depth is approximately 450 m, and in Siberia, depths exceeding 1500 m have been reported. etc.

SECONDARY YMP FEP NUMBER: 1.3.04.00.09
FEP NAME: Permafrost

ORIGINATOR FEP DESCRIPTION: Glaciation has been eliminated from performance assessment calculations on the basis of low probability of occurrence over the next 10,000 years. Similarly, a number of processes associated with the proximity of an ice sheet or valley glacier , such as permafrost and accelerated slope erosion (solifluction) have been eliminated from performance assessment calculations on the basis of low probability of occurrence over the next 10,000 years.

PRIMARY YMP FEP NUMBER: 1.3.05.00.00
FEP NAME: Glacial and ice sheet effects, local

ORIGINATOR FEP DESCRIPTION: Local glacial and ice sheet effects refers to FEPs related to the effects of glaciers and ice sheets within the region of a repository, e.g. changes in the geomorphology, erosion, melt water and hydraulic effects. This is distinct from the effect of large ice masses on global and regional climate, c.f. FEP 1.3.01.00.00.

YMP PRIMARY FEP DESCRIPTION: This category contains FEPs related to the effects of glaciers and ice sheets occurring within the region of the repository, including direct geomorphologic effects and hydrologic effects. These effects include changes in topography (due to glaciation and melt water), changes in flow fields, and isostatic depression and rebound.

SECONDARY YMP FEP NUMBER: 1.3.05.00.01
FEP NAME: Glaciation

ORIGINATOR FEP DESCRIPTION: Glaciation will change stress fields, flow regimes and temperatures. It could have many complex effects on processes occurring in the vault.

SECONDARY YMP FEP NUMBER: 1.3.05.00.02
FEP NAME: Glaciation

ORIGINATOR FEP DESCRIPTION: Glaciation may cause activation and creation of faults, changes in topography, changes in hydraulic heads, changes in groundwater recharge and discharge zones and isostatic depression. ETC.

SECONDARY YMP FEP NUMBER: 1.3.05.00.03
FEP NAME: Glaciation

ORIGINATOR FEP DESCRIPTION: During the past earth history there are many evidences for repeated glacial periods. Glacial and interglacial periods have followed each other. etc.

SECONDARY YMP FEP NUMBER: 1.3.05.00.04
FEP NAME: Glaciation

ORIGINATOR FEP DESCRIPTION: None

SECONDARY YMP FEP NUMBER: 1.3.05.00.05
FEP NAME: Glacial climate

ORIGINATOR FEP DESCRIPTION: A glacial climate marks the height of a glaciation and is characterized by the pressure of an ice mass on the landscape e.g. ice sheet, valley glacier. etc.

SECONDARY YMP FEP NUMBER: 1.3.05.00.06
FEP NAME: Glacial erosion/sedimentation

ORIGINATOR FEP DESCRIPTION: Erosion and sedimentation caused by glacial ice results in over deepening of valleys, scouring of upland areas, deposition of glacial moraines and modification of stream channel networks. etc.

SECONDARY YMP FEP NUMBER: 1.3.05.00.07
FEP NAME: Glacial-fluvial erosion/sedimentation

ORIGINATOR FEP DESCRIPTION: Erosion and deposition by glacial melt waters occurs early in interglacial periods. The process potentially results in down cutting of river channels, deposition of alluvium and glacial outwash and formation of stream terraces. etc.

SECONDARY YMP FEP NUMBER: 1.3.05.00.08
FEP NAME: Ice sheet effects (loading, melt water recharge)

ORIGINATOR FEP DESCRIPTION: A scenario that has been postulated in other studies is that, as the ice sheet advances then recharge will occur from the melt water formed under pressure at the base of the ice sheet. In the case of a static or retreating ice sheet, this water may escape as sub-glacial rivers between the ice and ground. etc.

SECONDARY YMP FEP NUMBER: 1.3.05.00.09
FEP NAME: Glaciation

ORIGINATOR FEP DESCRIPTION: The world's climate will for the next 100,000 years be featured by periods of glaciations, as it has been over similar periods for the past million years.

SECONDARY YMP FEP NUMBER: 1.3.05.00.10
FEP NAME: Glaciation

ORIGINATOR FEP DESCRIPTION: No evidence exists to suggest that the northern part of the Delaware Basin has been covered by continental glaciers at any time since the beginning of the Paleozoic Era. etc.

SECONDARY YMP FEP NUMBER: 1.3.05.00.11
FEP NAME: Glaciation

ORIGINATOR FEP DESCRIPTION: Continental glaciation may influence the disposal system and bring about massive disruptions in the biosphere.

SECONDARY YMP FEP NUMBER: 1.3.05.00.12
FEP NAME: Isostatic rebound

ORIGINATOR FEP DESCRIPTION: The presence of heavy loads on the earth's surface, such as several kilometers of glacial ice, may compress and depress underlying rock, followed by rebound effects when the load is removed.

PRIMARY YMP FEP NUMBER: 1.3.07.01.00
FEP NAME: Drought / water table decline

ORIGINATOR FEP DESCRIPTION: The current levels of meteoric precipitation could change substantially, leading to much less flow of water through the geosphere, with accompanying changes to the biosphere.

YMP PRIMARY FEP DESCRIPTION: Extreme climate change could produce an extended drought, leading to a decline in the water table in the saturated zone and affecting the release and exposure pathways from the repository.

SECONDARY YMP FEP NUMBER: 1.3.07.01.01
FEP NAME: Desert and unsaturation

ORIGINATOR FEP DESCRIPTION: Extreme climate change (perhaps human induced) could result in desaturation of the saturated zone, thereby affecting the release and exposure pathways from the repository.

SECONDARY YMP FEP NUMBER: 1.3.07.01.02
FEP NAME: Dust storms and desertification

ORIGINATOR FEP DESCRIPTION: The focus here is on large scale desertification as a result of extended drought. Thus, there could be deforestation and much of the grassland could also disappear. The exposed soil would erode and dust storms might become a common feature. etc.

PRIMARY YMP FEP NUMBER: 1.4.01.01.00
FEP NAME: Climate modification increases recharge

ORIGINATOR FEP DESCRIPTION: An increase in recharge at the repository site due to artificial climate change increases unsaturated flux through the repository.

YMP PRIMARY FEP DESCRIPTION: Climate modification causes an increase in recharge in the Yucca Mountain region. Increased recharge might lead to increased flux through the repository, perched water, or water table rise.

SECONDARY YMP FEP NUMBER: 1.4.01.01.01
FEP NAME: Climate modification causes perched water to develop at base of Topopah Spring unit

ORIGINATOR FEP DESCRIPTION: Climate modification causes an increased recharge producing perched water which develops at the base of the Topopah Spring nonwelded unit. Flow through the Calico Hills unit is fracture flow which drains the perched zone.

SECONDARY YMP FEP NUMBER: 1.4.01.01.02
FEP NAME: Climate modification causes perched water to develop above repository

ORIGINATOR FEP DESCRIPTION: Climate modification causes perched water conditions to develop above the repository, diverting downward flow through the repository in localized zones.

SECONDARY YMP FEP NUMBER: 1.4.01.01.03
FEP NAME: Climate modification raises water table

ORIGINATOR FEP DESCRIPTION: Deliberate human action to modify the climate raises the water table under Yucca Mtn., shortening the distance from the repository to the water table and therefore the residence of contaminants in the UZ.

SECONDARY YMP FEP NUMBER: 1.4.01.01.04
FEP NAME: Climate modification raises water table to flood repository

ORIGINATOR FEP DESCRIPTION: Increased recharge due to climate modification raises the regional water table sufficiently to flood the repository.

SECONDARY YMP FEP NUMBER: 1.4.01.01.05
FEP NAME: Climate modification raises water table to short circuit flow barrier in SZ

ORIGINATOR FEP DESCRIPTION: A higher water table due to climate modification short-circuits a flow barrier in the saturated zone, changing the pattern of flow.

PRIMARY YMP FEP NUMBER: 2.2.07.05.00
FEP NAME: Flow and transport in the UZ from episodic infiltration

ORIGINATOR FEP DESCRIPTION: Identified as "Unsaturated flow plume forms from infiltration and descends to interact with repository" by originator. An unsaturated flow plume (matrix flow w/o saturating pores) forms during an episodic precipitation event and descends to interact with the repository, either with the vaporization isotherm and condensate during the thermal period or entering the drifts in the post-thermal period.

YMP PRIMARY FEP DESCRIPTION: Episodic flow occurs in the UZ as a result of episodic infiltration. See also FEP 2.2.07.02.00 (unsaturated groundwater flow), 2.3.11.03.00 (infiltration), 2.2.07.04.00 (focusing of UZ flow), and 1.3.01.00.00 (climate change). Episodic flow may affect transport; for example, colloidal transport may be enhanced by episodic flow.

SECONDARY YMP FEP NUMBER: 2.2.07.05.01
FEP NAME: Episodic infiltration enhances colloid transport

ORIGINATOR FEP DESCRIPTION: Pulsed flow into the repository, resulting from episodic infiltration, can enhance the release and transport of colloids.

PRIMARY YMP FEP NUMBER: 2.2.07.06.00
FEP NAME: Episodic / pulse release from repository

ORIGINATOR FEP DESCRIPTION: None provided.

YMP PRIMARY FEP DESCRIPTION: Episodic release of radionuclides from the repository and radionuclide transport in the UZ may occur both because of episodic flow into the repository (see 2.2.07.05.00, episodic flow in UZ), and because of other factors including intermittent failures of waste packages.

SECONDARY YMP FEP NUMBER: None
FEP NAME: None

ORIGINATOR FEP DESCRIPTION: None

PRIMARY YMP FEP NUMBER: 2.2.07.07.00
FEP NAME: Perched water develops

ORIGINATOR FEP DESCRIPTION: Identified as "Perched water develops above repository" by originator. Perched water develops above the repository, diverting downward flow into fracture zones draining the perched water table.

YMP PRIMARY FEP DESCRIPTION: Zones of perched water may develop above the water table. If these zones occur above the repository, they may affect UZ flow between the surface and the waste packages. If they develop below the repository, for example at the base of the Topopah Spring welded unit, they may affect flow pathways and radionuclide transport between the waste packages and the saturated zone.

SECONDARY YMP FEP NUMBER: 2.2.07.07.01
FEP NAME: Perched water develops at base of Topopah Spring welded unit

ORIGINATOR FEP DESCRIPTION: Perched water develops at the base of the Topopah Spring welded unit. Flow through the Calico Hills is diverted into fracture zones draining the perched water table.

PRIMARY YMP FEP NUMBER: 2.3.11.03.00
FEP NAME: Infiltration and recharge (hydrologic and chemical effects)

ORIGINATOR FEP DESCRIPTION: None

YMP PRIMARY FEP DESCRIPTION: Infiltration into the subsurface provides a boundary condition for groundwater flow. The amount and location of the infiltration influences the hydraulic gradient and the height of the water table. Different sources of recharge water could change the chemistry of groundwaters passing through the repository. Mixing of these waters with other groundwaters could result in precipitation, dissolution and altered chemical gradients.

SECONDARY YMP FEP NUMBER: 2.3.11.03.01
FEP NAME: Freshwater intrusion (in geosphere)

ORIGINATOR FEP DESCRIPTION: A number of FEPs , including climate change, can result in changes in infiltration and recharge. These changes will affect the height of the water table and hence could affect groundwater flow in the Rustler through changes in head gradient. etc.

SECONDARY YMP FEP NUMBER: 2.3.11.03.02
FEP NAME: Groundwater recharge/discharge

ORIGINATOR FEP DESCRIPTION: Groundwater recharge and discharge may affect performance.

SECONDARY YMP FEP NUMBER: 2.3.11.03.03
FEP NAME: Equilibrated flow system

ORIGINATOR FEP DESCRIPTION: There is no net infiltration below a shallow depth. All infiltrating liquid either evaporates, is transpired, or is diverted in the near-surface away from the repository

SECONDARY YMP FEP NUMBER: 2.3.11.03.04
FEP NAME: Draining flow system

ORIGINATOR FEP DESCRIPTION: There is no net infiltration. The UZ is draining (despite current estimates of infiltration).

SECONDARY YMP FEP NUMBER: 2.3.11.03.05
FEP NAME: Recharge groundwater

ORIGINATOR FEP DESCRIPTION: Different sources of recharge water could change the chemistry of groundwaters passing through the vault. Mixing of these waters with other groundwaters could result in precipitation, dissolution and altered chemical gradients.

SECONDARY YMP FEP NUMBER: 2.3.11.03.06
FEP NAME: Surface water chemistry

ORIGINATOR FEP DESCRIPTION: Surface waters will determine the groundwater conditions in the upper most part of the rock, but can also enter deeper down in the geosphere by the existence or the formation of highly permeable fracture zones caused by tectonic movements or due to other changes in the stress field in the rock. etc.

SECONDARY YMP FEP NUMBER: 2.3.11.03.07
FEP NAME: Runoff is intercepted by wash terraces

ORIGINATOR FEP DESCRIPTION: Runoff passes over the terraces along the sides of washes, which represent past elevations of the wash, before reaching the active wash basin. Some runoff infiltrates into the terraces.
SECONDARY YMP FEP NUMBER: 2.3.11.03.08
FEP NAME: Runoff to washes infiltrates and maintains a zone of higher flux to the UZ

ORIGINATOR FEP DESCRIPTION: Runoff to washes infiltrates the wash bottom and a zone of higher moisture flux is maintained below the wash.

SECONDARY YMP FEP NUMBER: 2.3.11.03.09
FEP NAME: Flow in ephemeral streams tends to be in channels and is a source of recharge

ORIGINATOR FEP DESCRIPTION: Flow in washes, the result of runoff, tends to be in the wash channels where there is some seepage. This seepage is a source of recharge.

SECONDARY YMP FEP NUMBER: 2.3.11.03.10
FEP NAME: Percolation (near surface hydrology)

ORIGINATOR FEP DESCRIPTION: Percolation is the process of solute transport downwards in the soil profile. When P exceeds ETP, taking account of water storage capacity, solutes will move down the soil profile towards the aquifer.

SECONDARY YMP FEP NUMBER: 2.3.11.03.11
FEP NAME: Groundwater recharge

ORIGINATOR FEP DESCRIPTION: The DOE addresses issues related to groundwater flow and radionuclide transport within the context of a conceptual model of how the natural system works on a large scale.

SECONDARY YMP FEP NUMBER: 2.3.11.03.12
FEP NAME: Infiltration (near surface hydrology)

ORIGINATOR FEP DESCRIPTION: The DOE addresses issues related to groundwater flow and radionuclide transport within the context of a conceptual model of how the natural system works on a large scale.

SECONDARY YMP FEP NUMBER: 2.3.11.03.13
FEP NAME: Recharge groundwater (affects waste and EBS)

ORIGINATOR FEP DESCRIPTION: Different sources of recharge water or intrusion of saline water could affect the chemistry of the groundwaters passing through the vault.

SECONDARY YMP FEP NUMBER: 2.3.11.03.14
FEP NAME: Effective moisture (recharge)

ORIGINATOR FEP DESCRIPTION: Effective moisture is the net flux of water available for groundwater recharge, taking into account precipitation, evaporation, transpiration and run-off,and incorporating such climatic factors as temperature, cloud cover and humidity.

SECONDARY YMP FEP NUMBER: 2.3.11.03.15
FEP NAME: Changes in groundwater recharge and discharge

ORIGINATOR FEP DESCRIPTION: Changes in recharge may affect groundwater flow and radionuclide transport in units such as the Culebra and Magenta.

SECONDARY YMP FEP NUMBER: 2.3.11.03.16
FEP NAME: Coupling of surface water flow to climate/hydrologic modeling system

ORIGINATOR FEP DESCRIPTION: Analysis of the effects of surface water flow on the overall hydrologic system needs to be shown. The impact of rare, episodic surface water flow events (100-500 year floods) for current climate conditions, and overall enhanced surface water flow which will be much more significant for wetter climates.

ATTACHMENT IV

EROSION/DISSOLUTON/SUBSIDENCE FEPS DESCRIPTIONS

PRIMARY YMP FEP NUMBER: 1.2.07.01.00
FEP NAME: Erosion/denudation

ORIGINATOR FEP DESCRIPTION: Erosion and denudation are processes which cause significant changes in the present-day topography and thus affect local and regional hydrology and the biosphere. The extent of erosion depends to a large extent on climate and uplift.

YMP PRIMARY FEP DESCRIPTION: Erosion and denudation are processes which cause significant changes in the present-day topography and thus affect local and regional hydrology and the biosphere. Erosion of surficial materials can occur by a variety of means, including physical weathering (including glacial and fluvial erosion), chemical weathering, erosion by wind (aeolian erosion), and mass wasting (e.g., landslide) processes. The extent of erosion depends to a large extent on climate and uplift.

SECONDARY YMP FEP NUMBER: 1.2.07.01.01
FEP NAME: Major incision

ORIGINATOR FEP DESCRIPTION: Any mechanism which may cut a deep channel into surface rocks. A deep incision may affect the groundwater flow patterns and may reduce the distance from repository to biosphere for radionuclide transport. ... The only mechanism likely to cause major incision is thought to be glacial erosion.

SECONDARY YMP FEP NUMBER: 1.2.07.01.02
FEP NAME: Generalized denudation

ORIGINATOR FEP DESCRIPTION: The erosion of the land-surface on a regional scale due to glacial, fluvial and aeolian processes.

SECONDARY YMP FEP NUMBER: 1.2.07.01.03
FEP NAME: Localized denudation

ORIGINATOR FEP DESCRIPTION: The erosion of the land-surface on a local scale due to glacial, fluvial and coastal processes.

SECONDARY YMP FEP NUMBER: 1.2.07.01.04
FEP NAME: Solid discharge via erosional processes

ORIGINATOR FEP DESCRIPTION: Dissolved radionuclides migrating in the far-field will contaminate the far-field rock by sorptive and retardation processes. ... Contaminated far-field rocks will be exhumed by normal denudation processes and the rock's radionuclide load will enter the biosphere.

SECONDARY YMP FEP NUMBER: 1.2.07.01.05
FEP NAME: Basement alteration

ORIGINATOR FEP DESCRIPTION: Local removal of the sedimentary cover and the southward shift of the Rhine may result in changes to the hydrologic regime in the basement, especially in the higher-permeability domain. The nearer-surface crystalline basement has been progressively altered in the past as a result of stress field and rock-water interactions, especially hydrothermal alteration, which has been more significant in the higher-permeability domain than in the low-permeability domain. etc.

SECONDARY YMP FEP NUMBER: 1.2.07.01.06
FEP NAME: Hydraulic gradient changes (magnitude, direction) (in geosphere)

ORIGINATOR FEP DESCRIPTION: As a result of continuing action of geological processes, the future surface geology of Northern Switzerland will be different to the present one. The effect of certain erosion processes, such as removal of the Quaternary gravels or denudation (uniform erosion to a maximum of 100m), are not expected to be hydraulically relevant for groundwater flow in the crystalline basement.

SECONDARY YMP FEP NUMBER: 1.2.07.01.07
FEP NAME: Hydraulic gradient changes (magnitude, direction)

ORIGINATOR FEP DESCRIPTION: As a result of continuing action of geological processes, the future surface geology of Northern Switzerland will be different to the present one. The effect of certain erosion processes, such as removal of the Quaternary gravels or denudation(uniform erosion to a maximum of 100m), are not expected to be hydraulically relevant for groundwater flow in the crystalline basement.

SECONDARY YMP FEP NUMBER: 1.2.07.01.08
FEP NAME: Ephemeral stream erosion cuts Tiva Canyon units to underlying nonwelded units

ORIGINATOR FEP DESCRIPTION: Beds of intermittent streams now resting on the Tiva Canyon welded tuff unit erode through to the underlying nonwelded unit. These washes form a barrier to lateral flow in the Tiva Canyon and divert flow downward. Regions of high flux are formed below them.

SECONDARY YMP FEP NUMBER: 1.2.07.01.09
FEP NAME: Land slide

ORIGINATOR FEP DESCRIPTION: None.

SECONDARY YMP FEP NUMBER: 1.2.07.01.10
FEP NAME: Stream erosion of Amargosa River lowers base levels and increases gradient in SZ

ORIGINATOR FEP DESCRIPTION: *Entrenchment of the Amargosa River at Alkali Flat lowers base levels and increases regional gradients. Regional hydraulic relations are such that water-table lowering at Yucca Mountain is insignificant, but increases in groundwater velocity are significant.*

SECONDARY YMP FEP NUMBER: 1.2.07.01.11
FEP NAME: Erosion

ORIGINATOR FEP DESCRIPTION: Massive erosion of rock (by glaciation or water) could result in significant changes to hydraulic heads and a shorter transport path for contaminants.

SECONDARY YMP FEP NUMBER: 1.2.07.01.12
FEP NAME: Erosion - lateral transport

ORIGINATOR FEP DESCRIPTION: Erosion of soil, overburden and bedrock by wind, water or ice may move contaminating radionuclides laterally away from the area occupied by the critical group and reduce local contamination.

SECONDARY YMP FEP NUMBER: 1.2.07.01.13
FEP NAME: Erosion (wind)

ORIGINATOR FEP DESCRIPTION: Soil and other materials contaminated with radionuclides may be exposed and eroded by wind action, and dispersed in the environment. This would remove radioactivity from the area occupied by the critical group, particularly because radionuclides tend to adhere to small clay particles which are more easily carried away than bulk soil.

SECONDARY YMP FEP NUMBER: 1.2.07.01.14
FEP NAME: Erosion on surface/sediments

ORIGINATOR FEP DESCRIPTION: Erosion of surface sediments (and crystalline bedrock) is a continuously ongoing process due to weathering. etc.

SECONDARY YMP FEP NUMBER: 1.2.07.01.15
FEP NAME: Denudation

ORIGINATOR FEP DESCRIPTION: None.

SECONDARY YMP FEP NUMBER: 1.2.07.01.16
FEP NAME: River, stream channel erosion

ORIGINATOR FEP DESCRIPTION: None.

SECONDARY YMP FEP NUMBER: 1.2.07.01.17
FEP NAME: Chemical denudation and weathering

ORIGINATOR FEP DESCRIPTION: None.

SECONDARY YMP FEP NUMBER: 1.2.07.01.18
FEP NAME: Erosion

ORIGINATOR FEP DESCRIPTION: As a result of continuing action of geological processes, the future surface geology of Northern Switzerland will be different to the present one. The effect of certain erosion processes, such as the removal of Quaternary gravels or denudation(uniform erosion--max. 100 m), are not expected to be hydraulically relevant for groundwater flow in the HPD. etc.

SECONDARY YMP FEP NUMBER: 1.2.07.01.19
FEP NAME: Erosion/deposition

ORIGINATOR FEP DESCRIPTION: Erosion/deposition (fluvial, glacial or glacial-fluvial) in the biosphere (alluvium of the Rhine river valley) is affected by both geologic and climatic FEPs (see geologic and climatic domains, sections 9 and 10). ... These processes may significantly affect the transport mechanism for radionuclides in the biosphere, over long timescales.

SECONDARY YMP FEP NUMBER: 1.2.07.01.20
FEP NAME: Fluvial erosion/sedimentation

ORIGINATOR FEP DESCRIPTION: Fluvial erosion/sedimentation is affected by climatic factors as well as geological factors-the impact on domains depends on the net amount of fluvial erosion/sediment caused by these two controlling factors. etc.

SECONDARY YMP FEP NUMBER: 1.2.07.01.21
FEP NAME: Surface denudation

ORIGINATOR FEP DESCRIPTION: Surface denudation is caused by surface loosening and intensive in-situ weathering brought about by a range of factors including, large temperature fluctuations, permafrost, changes in vegetation, etc. ... The corresponding erosion potential in Northern Switzerland is estimated to be 50m per million years for an arid climate, and 100m per million years for a humid/glacial climate.

SECONDARY YMP FEP NUMBER: 1.2.07.01.22
FEP NAME: Chemical weathering

ORIGINATOR FEP DESCRIPTION: Chemical weathering is assumed to be occurring at or near the surface around the WIPP site, through processes such as exfoliation and leaching. The extent of this process is limited and will contribute little to the overall rate of erosion in the area or to the availability of material for other erosional processes. etc.

SECONDARY YMP FEP NUMBER: 1.2.07.01.23
FEP NAME: Aeolian erosion

ORIGINATOR FEP DESCRIPTION: The geomorphological regime on the Mescalero Plain (Los Medanos) in the region of the WIPP is dominated by aeolian processes. Dunes are present in the area, and although some are stabilized by vegetation, aeolian erosion will occur as they migrate across the area. etc.

SECONDARY YMP FEP NUMBER: 1.2.07.01.24
FEP NAME: Fluvial erosion

ORIGINATOR FEP DESCRIPTION: Currently, precipitation in the region of WIPP is too low (about 13 inches per year) to cause perennial streams, and the relief in the area is too low for extensive sheet flood erosion during storms. etc.

SECONDARY YMP FEP NUMBER: 1.2.07.01.25
FEP NAME: Mass wasting

ORIGINATOR FEP DESCRIPTION: Mass wasting (the down slope movement of material caused by the direct effect of gravity) is important only in terms of sediment erosion in regions of steep slopes. In the vicinity of WIPP, mass wasting will be insignificant under the climatic conditions expected over the next 10,000 years. etc.

SECONDARY YMP FEP NUMBER: 1.2.07.01.26
FEP NAME: Mass wasting

ORIGINATOR FEP DESCRIPTION: Mass wasting may be significant for sedimentary deposition if it results in dams or modifies streams. In the region around WIPP, the Pecos River forms a significant water course some 12 miles away, but the broadness of the valley precludes either significant mass wasting or the formation of large impoundments.

SECONDARY YMP FEP NUMBER: 1.2.07.01.27
FEP NAME: Mechanical weathering

ORIGINATOR FEP DESCRIPTION: Mechanical weathering is assumed to be occurring at or near the surface around the WIPP site, through processes such as exfoliation and leaching. The extent of this processes is limited and will contribute little to the overall rate of erosion in the area or to the availability of material for other erosional processes. The effects of mechanical weathering have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.
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PRIMARY YMP FEP NUMBER: 1.2.07.02.00
FEP NAME: Deposition

ORIGINATOR FEP DESCRIPTION: (Identified as "Fluvial deposition" by originator) The limited extent of water courses in the region of the WIPP, under both present-day conditions and under the expected climatic conditions, will restrict the amount of fluvial deposition in the region.

YMP PRIMARY FEP DESCRIPTION: Deposition and erosion are processes which cause significant changes in the present-day topography and thus affect local and regional hydrology and the biosphere. Deposition of surficial materials can occur by a variety of means, including fluvial, aeolian, and lacustrine deposition and redistribution of soil through weathering and mass wasting processes.

SECONDARY YMP FEP NUMBER: 1.2.07.02.01
FEP NAME: Aeolian deposition

ORIGINATOR FEP DESCRIPTION: The geomorphological regime on the Mescalero Plain (Los Medanos) in the region of the WIPP is dominated by aeolian processes but, although some dunes are stabilized by vegetation, no significant changes in overall thickness of aeolian material are expected to occur. etc.

SECONDARY YMP FEP NUMBER: 1.2.07.02.02
FEP NAME: Lacustrine deposition

ORIGINATOR FEP DESCRIPTION: The limited extent of water courses in the region of WIPP, under both present-day conditions and under the expected climatic conditions, will restrict the amount of lacustrine deposition in the region.

PRIMARY YMP FEP NUMBER: 1.2.09.02.00
FEP NAME: Large-scale dissolution

ORIGINATOR FEP DESCRIPTION: (Identified as "Deep dissolution" by originator) Deep dissolution takes place in the Castile and the base of the Salado. Deep dissolution refers to the dissolution of salt or other evaporite minerals in a formation at depth. etc. (WIPP)

YMP PRIMARY FEP DESCRIPTION: Dissolution can occur when any soluble mineral is removed by flowing water, and large-scale dissolution is a potentially important process in rocks that are composed predominantly of water-soluble evaporite minerals, such as salt.

SECONDARY YMP FEP NUMBER: 1.2.09.02.01
FEP NAME: Shallow dissolution

ORIGINATOR FEP DESCRIPTION: Shallow dissolution involves percolation of groundwater and mineral dissolution in the Rustler. ... Extensive dissolution may create cavities (karst) and result in the total collapse of overlying units.

SECONDARY YMP FEP NUMBER: 1.2.09.02.02
FEP NAME: Lateral dissolution

ORIGINATOR FEP DESCRIPTION: Lateral dissolution involves dissolution at the top of the Salado. ... Lateral dissolution takes place when percolating groundwater dissolves halite at the top of the Salado, causing collapse of the overlying Rustler with consequent changes in hydrogeological properties. etc.

SECONDARY YMP FEP NUMBER: 1.2.09.02.03
FEP NAME: Solution chimneys

ORIGINATOR FEP DESCRIPTION: Deep dissolution takes place in the Castile and the base of the Salado. ... Dissolution by groundwater from deep water-bearing zones can lead to formation of cavities. If dissolution is extensive, breccia pipes or solution chimneys may form above the cavity. etc.

SECONDARY YMP FEP NUMBER: 1.2.09.02.04
FEP NAME: Breccia pipes

ORIGINATOR FEP DESCRIPTION: Deep dissolution takes place in the Castile and the base of the Salado. ... Dissolution by groundwater from deep water-bearing zones can lead to formation of cavities. If dissolution is extensive, breccia pipes or solution chimneys may form above the cavity. ... These pipes may reach the surface or pass upwards into fractures and then into micro cracks that do not extend to the surface. etc.

SECONDARY YMP FEP NUMBER: 1.2.09.02.05
FEP NAME: Collapse breccias

ORIGINATOR FEP DESCRIPTION: ... Collapse breccias are present at several places around the margin of the Delaware Basin. Their formation is attributed to relatively fresh groundwater from the Capitan Limestone that forms the margin of the basin. etc.

PRIMARY YMP FEP NUMBER: 2.2.06.04.00
FEP NAME: Effects of subsidence

ORIGINATOR FEP DESCRIPTION: Identified as "Subsidence of mined facility alters drainage" by originator. Subsidence of the mined underground facility creates impoundments or diverts drainage, thereby increasing the local percolation flux to values not currently seen.

YMP PRIMARY FEP DESCRIPTION: Subsidence above the mined underground facility or other openings affects the properties of the overlying rocks and surface topography. Changes in rock properties, such as enhanced permeability, may alter flow paths from the surface to the repository. Changes in surface topography may alter run-off and infiltration, and may perhaps create impoundments.

SECONDARY YMP FEP NUMBER: 2.2.06.04.01
FEP NAME: *Subsidence*

ORIGINATOR FEP DESCRIPTION: Subsidence through salt creep or roof collapse associated with excavation might affect the hydrologic properties of units above the repository.

SECONDARY YMP FEP NUMBER: 2.2.06.04.02
FEP NAME: *Large-scale rock fracturing*

ORIGINATOR FEP DESCRIPTION: Subsidence through salt creep or roof collapse associated with excavation might cause large-scale rock fracturing between the repository horizon and the surface.

SECONDARY YMP FEP NUMBER: 2.2.06.04.03
FEP NAME: *Borehole-induced solution and subsidence*

ORIGINATOR FEP DESCRIPTION: Potentially, boreholes could provide pathways for surface-derived water or groundwater to percolate through low-permeability strata and into formations containing soluble minerals. Large-scale dissolution through this mechanism could lead to subsidence and to changes in groundwater flow patterns.

ATTACHMENT V

HUMAN INFLUENCES ON CLIMATE/SOIL FEPS DESCRIPTIONS

PRIMARY YMP FEP NUMBER: 1.4.01.00.00
FEP NAME: Human influences on climate

ORIGINATOR FEP DESCRIPTION: Human influences on climate refers to FEPs related to human activities that could affect the change of climate either globally or in a region.

YMP PRIMARY FEP DESCRIPTION: This category contains FEPs related to future human actions that could influence global, regional, or local climate. Human actions may be intentional or accidental. This FEP aggregates all human influences on climate into a single category. Technical discussions are presented separately for increased recharge (1.4.01.01.00), greenhouse gas effects (1.4.01.02.00), acid rain (1.4.01.03.00), and ozone layer failure (1.4.01.04.00).

SECONDARY YMP FEP NUMBER: 1.4.01.00.01
FEP NAME: Human-induced climate change

ORIGINATOR FEP DESCRIPTION: Climate alteration, intentional or accidental, produced by human actions.

SECONDARY YMP FEP NUMBER: 1.4.01.00.02
FEP NAME: Anthropogenic climate change

ORIGINATOR FEP DESCRIPTION: None

SECONDARY YMP FEP NUMBER: 1.4.01.00.03
FEP NAME: Human-induced climate change

ORIGINATOR FEP DESCRIPTION: The impact of anthropogenic greenhouse gases (e.g. CO2, CH4,etc.) on the climate is unclear. However the general consensus is that anthropogenically induced climate forcing will/may marginally delay but not prevent a next ice age. etc.

SECONDARY YMP FEP NUMBER: 1.4.01.00.04
FEP NAME: Climate change: Human induced

ORIGINATOR FEP DESCRIPTION: Changes to climate due to human activities, e.g. release of greenhouse gases to the atmosphere. etc.

PRIMARY YMP FEP NUMBER: 1.4.01.02.00
FEP NAME: Greenhouse gas effects

ORIGINATOR FEP DESCRIPTION: (Identified as "greenhouse effect" by originator)
The greenhouse effect could increase concentrations of carbon dioxide and other gases in the atmosphere, and lead to changes in climate at the disposal site.

YMP PRIMARY FEP DESCRIPTION: The greenhouse effect refers to the presence of carbon dioxide and other gases in the atmosphere that tend to allow solar radiation through to the earth's surface and reflect heat back to it. Thus, these gases act much as the glass of a greenhouse, with the earth as the greenhouse. Human activities such as burning of fossil fuels, forest clearance, and industrial processes produce these greenhouse gases. The greenhouse effect could increase concentrations of carbon dioxide and other gases in the atmosphere, and lead to changes in climate such as global warming.

SECONDARY YMP FEP NUMBER: 1.4.01.02.01
FEP NAME: Greenhouse effect

ORIGINATOR FEP DESCRIPTION: The greenhouse effect refers to the presence of carbon dioxide and other gases in the atmosphere that tend to allow solar radiation through to the earth's surface and reflect heat back to it. Thus, these gases act much as the glass of a greenhouse, with the earth as the greenhouse. A key concern of a significant human-produced increase in these gases in the atmosphere over the last 150 years is massive climatic change. For the Shield, this might mean a warmer and drier climate for, perhaps, hundreds of years. The duration of the stronger greenhouse effect would depend on further contributions to the greenhouse gases, such as from burning fossil fuels, and the rate of disappearance of the gases into peat, the seas and sedimentary deposits.

SECONDARY YMP FEP NUMBER: 1.4.01.02.02
FEP NAME: Greenhouse gas effects

ORIGINATOR FEP DESCRIPTION: ... The effects of anthropogenic climate change may be on a local to regional scale(acid rain) or on a regional to global scale (greenhouse gas effects and damage to the ozone layer). Of these anthropogenic effects, only the greenhouse gas effect could influence groundwater recharge in the WIPP region. However, consistent with the future states assumptions in 40 CFR 194.25(a), compliance assessments and performance assessments need not consider indirect anthropogenic effects on disposal performance.

SECONDARY YMP FEP NUMBER: 1.4.01.02.03
FEP NAME: Greenhouse gas effects

ORIGINATOR FEP DESCRIPTION: Global changes in climate and sea levels caused by a warming of the atmosphere may occur due to the release of gases, principally carbon dioxide but also chlorofluorocarbons (CFCs) and water vapor, through human activities (e.g., burning of fossil fuels, forest clearance, industrial processes). If this effect becomes significant markedly warmer climate states are predicted for northern Switzerland.

PRIMARY YMP FEP NUMBER: 1.4.01.03.00
FEP NAME: Acid rain

ORIGINATOR FEP DESCRIPTION: ... The effects of anthropogenic climate change may be on a local to regional scale (acid rain) or on a regional to global scale (greenhouse gas effects and damage to the ozone layer). Of these anthropogenic effects, only the greenhouse gas effect could influence groundwater recharge in the WIPP region. However, consistent with the future states assumptions in 40 CFR 194.25(a), compliance assessments and performance assessments need not consider indirect anthropogenic effects on disposal performance.

YMP PRIMARY FEP DESCRIPTION: Human actions may result in acid rain on a local to regional scale. Acid rain can detrimentally affect aquatic and terrestrial life by interfering with the growth, reproduction and survival of organisms. It can influence the behavior and transport of contaminants in the biosphere, particularly by affecting surface water and soil chemistry.

SECONDARY YMP FEP NUMBER: 1.4.01.03.01
FEP NAME: Acid rain

ORIGINATOR FEP DESCRIPTION: Acid rain can detrimentally affect aquatic and terrestrial life by interfering with the growth, reproduction and survival of organisms. It can influence the behavior and transport of contaminants in the biosphere, particularly in surface water and soil.

SECONDARY YMP FEP NUMBER: 1.4.01.03.02
FEP NAME: Surface water pH

ORIGINATOR FEP DESCRIPTION: In conjunction with acid rain, the pH of water bodies on the Shield has become of major concern. ... The pH can also influence sedimentation of contaminants through the availability of suspended particles and the reaction of contaminants with these particles. etc.

PRIMARY YMP FEP NUMBER: 1.4.01.04.00
FEP NAME: Ozone layer failure

ORIGINATOR FEP DESCRIPTION: Certain industrial chemicals may lead to the destruction of the earth's ozone layer. Without an ozone layer, UV could penetrate readily down to the earth's surface, which would constitute an increase in solar radiation.

YMP PRIMARY FEP DESCRIPTION: Human actions (i.e., the use of certain industrial chemicals) may lead to destruction or damage to the earth's ozone layer. This may lead to significant changes to the climate, affecting properties of the geosphere such as groundwater flow patterns.

SECONDARY YMP FEP NUMBER: 1.4.01.04.01
FEP NAME: Damage to the ozone layer

ORIGINATOR FEP DESCRIPTION: ... The effects of anthropogenic climate change may be on a local to regional scale (acid rain) or on a regional to global scale (greenhouse gas effects and damage to the ozone layer). Of these anthropogenic effects, only the greenhouse gas effect could influence groundwater recharge in the WIPP region. However, consistent with the future states assumptions in 40 CFR 194.25(a), compliance assessments and performance assessments need not consider indirect anthropogenic effects on disposal performance.

SECONDARY YMP FEP NUMBER: 1.4.01.04.02
FEP NAME: Ozone layer

ORIGINATOR FEP DESCRIPTION: Destruction or damage to the earth's ozone layer may lead to significant changes to the climate, affecting properties of the geosphere such as groundwater flow patterns.

PRIMARY YMP FEP NUMBER: 1.4.06.01.00
FEP NAME: Altered soil or surface water chemistry

ORIGINATOR FEP DESCRIPTION: (Identified as "Altered surface water chemistry" by originator) The industrial pollution could give rise to considerable change in surface water chemistry by acidic rain, increased atmospheric carbon dioxide content, complexing agents in the surface waters,etc.

YMP PRIMARY FEP DESCRIPTION: Human activities (e.g., industrial pollution, agricultural chemicals) may produce local changes to the soil chemistry or to the chemistry of water infiltrating Yucca Mtn and could provide a plume of unspecified nature to interact with the repository and possibly with containers.

SECONDARY YMP FEP NUMBER: 1.4.06.01.01
FEP NAME: Altered soil or surface water chemistry

ORIGINATOR FEP DESCRIPTION: None.

SECONDARY YMP FEP NUMBER: 1.4.06.01.02
FEP NAME: Groundwater pollution

ORIGINATOR FEP DESCRIPTION: Human activity unrelated to the repository may result in pollution of the groundwaters, surface waters, soils and sediments. In the case of groundwater pollution, contaminants could change the geochemistry of the higher-permeability domain basement rock, and hence affect the speciation, solubility and sorption of radionuclides released from the repository. etc.

SECONDARY YMP FEP NUMBER: 1.4.06.01.03
FEP NAME: Surface pollution (soils, rivers)

ORIGINATOR FEP DESCRIPTION: Human activity unrelated to the repository may result in pollution of the groundwaters, surface waters, soils and sediments. In the case of groundwater pollution, contaminants could change the geochemistry of the higher-permeability domain basement rock, and hence affect the speciation, solubility and sorption of radionuclides released from the repository. etc.

SECONDARY YMP FEP NUMBER: 1.4.06.01.04
FEP NAME: Altered soil or surface water chemistry by human activities

ORIGINATOR FEP DESCRIPTION: Potash mining effluent and runoff from oil fields have altered soil and surface water chemistry in the vicinity of the WIPP. However, the performance of the disposal will not be sensitive to soil and surface water chemistry. Therefore, altered soil and surface water chemistry by human activities have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

SECONDARY YMP FEP NUMBER: 1.4.06.01.05
FEP NAME: Far field hydrochemistry - acids, oxidants, nitrate

ORIGINATOR FEP DESCRIPTION: The geochemistry might be changed by inflow of chemicals from the surface.

SECONDARY YMP FEP NUMBER: 1.4.06.01.06
FEP NAME: Arable farming

ORIGINATOR FEP DESCRIPTION: ... Agricultural activities could affect infiltration and recharge conditions in the vicinity of the WIPP. Also, application of acids, oxidants, and nitrates during agricultural practice could alter groundwater geochemistry. The EPA has provided criteria relating to future human activities in 40 CFR 194.32(a), that limit the scope of consideration of future human activities in performance assessments to mining and drilling. etc.

ATTACHMENT VI

NATURAL GAS/GAS GENERATION EFFECTS FEPS DESCRIPTIONS

PRIMARY YMP FEP NUMBER: 2.1.12.01.00
FEP NAME: Gas generation

ORIGINATOR FEP DESCRIPTION: (Identified as "Gas generation due to corrosion (chemical and/or microbial), radiolysis and radioactive decay" by originator)
Gas is generated by various mechanisms.

YMP PRIMARY FEP DESCRIPTION: Gas may be generated in the repository by a variety of mechanisms. Gas generation might lead to pressurization of the repository, produce multiphase flow, and affect radionuclide transport. This FEP aggregates all types of gas generation into a single category. Technical discussions are presented separately for gas generation from fuel decay (FEP 2.1.12.02.00), corrosion (FEP 2.1.12.03.00), microbial degradation (FEP 2.1.12.04.00), and radiolysis (FEP 2.1.13.01.00).

SECONDARY YMP FEP NUMBER: 2.1.12.01.01
FEP NAME: Formation of gases (in wastes and EBS)

ORIGINATOR FEP DESCRIPTION: Chemical reactions such as radiolysis and corrosion of iron may lead to the formation of gases such as hydrogen, oxygen and hydrogen sulfide. Gas pressure could act as a driving force to expel contaminated water from the vault or to prevent the ingress of water.

SECONDARY YMP FEP NUMBER: 2.1.12.01.02
FEP NAME: Gas generation

ORIGINATOR FEP DESCRIPTION: Gas generation could be caused by radiolysis, helium production, carbon dioxide, organic decomposition, corrosion or changing water chemistry.

SECONDARY YMP FEP NUMBER: 2.1.12.01.03
FEP NAME: Gas generation, buffer/backfill

ORIGINATOR FEP DESCRIPTION: Radiolytic decomposition of water in the vicinity of the canister may lead to hydrogen formation in the buffer, and microbial degradation of organics may lead to generation of hydrogen, carbon dioxide and methane in the bentonite buffer and in the backfill. etc.

SECONDARY YMP FEP NUMBER: 2.1.12.01.04
FEP NAME: Chemotoxic gases (in waste and EBS)

ORIGINATOR FEP DESCRIPTION: Production of chemotoxic gases that may influence other processes in the repository near-field, far-field or biosphere with radiological consequences. The health effects of chemotoxicity are not, themselves, of concern in this assessment.

SECONDARY YMP FEP NUMBER: 2.1.12.01.05
FEP NAME: Pressurization (in waste and EBS)

ORIGINATOR FEP DESCRIPTION: Increased gas pressure may slow the rate of salt creep. Closure and consolidation can be slowed by fluid pressure in the repository.

PRIMARY YMP FEP NUMBER: 2.2.10.11.00
FEP NAME: Natural air flow in unsaturated zone

ORIGINATOR FEP DESCRIPTION: Natural convective air circulation has been observed at a borehole at the top of the mountain. Repository heat is expected to increase this flow.

YMP PRIMARY FEP DESCRIPTION: Natural convective air circulation has been observed at a borehole at the top of the mountain. Repository heat is expected to increase this flow.

PRIMARY YMP FEP NUMBER: 2.2.11.01.00
FEP NAME: Naturally-occurring gases in geosphere

ORIGINATOR FEP DESCRIPTION: (Identified as "Effects of natural gases" by originator) Natural gases may be generated in the vicinity of the repository, or may migrate towards the repository from a source elsewhere. In extreme conditions, these gases may influence groundwater flow paths and releases to the biosphere.

YMP PRIMARY FEP DESCRIPTION: Naturally-occurring gases in the geosphere may intrude into the repository or may influence groundwater flow paths and releases to the biosphere. Potential sources for gas might be clathrates, microbial degradation of organic material or deep gases in general.

SECONDARY YMP FEP NUMBER: 2.2.11.01.01
FEP NAME: Methane intrusion (in geosphere)

ORIGINATOR FEP DESCRIPTION: The potential sources might be clathrates in combination with permafrost or deep earth gases in general.

SECONDARY YMP FEP NUMBER: 2.2.11.01.02
FEP NAME: Natural gas intrusion

ORIGINATOR FEP DESCRIPTION: None.

SECONDARY YMP FEP NUMBER: 2.2.11.01.03
FEP NAME: Geogas

ORIGINATOR FEP DESCRIPTION: Geogas may be present in the repository environment. Preliminary studies of the Swedish system indicate the existence of a geogas flow(probably nitrogen) and that matter is likely to be transported by geogas to the surface. Such transport is likely to be selective, favoring the upward transport of colloids and other small particles. etc.

SECONDARY YMP FEP NUMBER: 2.2.11.01.04
FEP NAME: Geogas

ORIGINATOR FEP DESCRIPTION: Geogas may be present in the repository environment. Preliminary studies of the Swedish system indicate the existence of a geogas flow(probably nitrogen) and that matter is likely to be transported by geogas to the surface. Such transport is likely to be selective, favoring the upward transport of colloids and other small particles. etc.

SECONDARY YMP FEP NUMBER: 2.2.11.01.05
FEP NAME: Gas generation and gas sources, far-field

ORIGINATOR FEP DESCRIPTION: Concerns the gas generation and the sources for gas in the geosphere. One of the sources is gas generated in the near-field of the repository and transported to the far-field. Other potential sources for gas might be clathrates, microbial degradation of organic material or deep gases in general.

SECONDARY YMP FEP NUMBER: 2.2.11.01.06
FEP NAME: Natural gas intrusion

ORIGINATOR FEP DESCRIPTION: Hydrocarbon resources are present in formations beneath the WIPP, and natural gas is extracted from the Morrow Formation. These reserves are, however, some 14,000 feet (4,200 meters) below the surface, and no natural events or processes have been identified that could result in natural gas intrusion into the Salado or the units above.

SECONDARY YMP FEP NUMBER: 2.2.11.01.07
FEP NAME: Methane

ORIGINATOR FEP DESCRIPTION: Methane in deep groundwaters may be a resource and the object of mining activities, or methane may modify the mobility of contaminants (methylation).

PRIMARY YMP FEP NUMBER: 2.2.11.02.00
FEP NAME: Gas Pressure effects

ORIGINATOR FEP DESCRIPTION: Since hydrostatic pressure is much greater than any likely pressure variations due to gas generation, significant changes in flow systems are unlikely to result.

YMP PRIMARY FEP DESCRIPTION: Pressure variations due to gas generation may affect flow patterns and contaminant transport in the geosphere.

SECONDARY YMP FEP NUMBER: 2.2.11.02.01
FEP NAME: Gas pressure effects

ORIGINATOR FEP DESCRIPTION: Since hydrostatic pressure is much greater than any likely pressure variations due to gas generation, significant changes in flow systems are unlikely to result.

SECONDARY YMP FEP NUMBER: 2.2.11.02.02
FEP NAME: Fluid flow due to gas pressurization (in waste and EBS)

ORIGINATOR FEP DESCRIPTION: Brine contained in the Salado may flow to the waste disposal region because of pressure gradients created by the excavation. Brine flow into the repository may be reduced as repository pressure increases, and brine may be expelled from the repository if pressure in the repository exceeds brine pressure in the immediately surrounding rock or borehole. Gas may be generated as waste decomposes, causing a pressure increase. Gas may flow away from the waste into lower pressure areas, which may include disturbed areas surrounding the repository, the interbeds, the shafts, or an intrusion borehole. Gas may not be able to flow through intact, halite-rich strata of the Salado under realistic conditions for the repository. Gas flow in liquid-saturated rock depends on the gas pressure required to overcome capillary resistance to initial gas penetration and development of interconnected gas pathways that allow gas flow (threshold pressure). While the permeability of halite is known to be low, its threshold pressure has never been measured. An empirical relationship between threshold pressure and permeability in non-WIPP rocks (Davies 1991, 17-19) suggests that threshold pressure will be sufficiently high that gas will not be able to flow through the halite-rich strata of the Salado under any conditions foreseeable for the WIPP. Values used by the DOE for halite threshold pressure are consistent for generic material of low permeability and prevent the flow of gas into the impure halite regions. etc.

SECONDARY YMP FEP NUMBER: 2.2.11.02.03
FEP NAME: Disruption due to gas effects

ORIGINATOR FEP DESCRIPTION: [The exact point of this FEP is well disguised in detailed text, but appears to be: brine flows between the repository and Salado via these interbeds, with separation of gas phases from brine which produces fracturing.]

PRIMARY YMP FEP NUMBER: 2.2.11.03.00
FEP NAME: Gas transport in geosphere

ORIGINATOR FEP DESCRIPTION: (Identified as "Gas flow and transport, near-field rock/far field" by originator) Gas released from the buffer and backfill and gas generated in the near-field rock will flow through fracture systems in the near-field rock and in the geosphere. Gas may dissolve in the groundwater and be transported by moving water, but as the pressure decreases in the rising groundwater flow gas may again form. If the gas carries radionuclides in gaseous state, this is a fast transport mechanism through the geosphere barrier for these nuclides.

YMP PRIMARY FEP DESCRIPTION: Gas released from the drifts and gas generated in the near-field rock will flow through fracture systems in the near-field rock and in the geosphere. Certain gaseous or volatile radionuclides may be able to migrate through the far-field faster than the groundwater advection rate. Degassing could affect flow and transport of gaseous contaminants. Gases could also affect other contaminants if water flow is driven by large gas bubbles forming in the repository.

SECONDARY YMP FEP NUMBER: 2.2.11.03.01
FEP NAME: Gases and gas transport (in geosphere)

ORIGINATOR FEP DESCRIPTION: Contaminants that are volatile or that form gases, or other gases such as hydrogen from corrosion of steel, may be transported as gases or in two phase flow. Degassing could therefore affect flow and transport of these contaminants. It could also affect other contaminants if water flow is driven by large gas bubbles forming in the vault.

SECONDARY YMP FEP NUMBER: 2.2.11.03.02
FEP NAME: Far-field transport: Gas induced groundwater transport

ORIGINATOR FEP DESCRIPTION: Two phase flow (gas and groundwater) occurring in the far-field may affect the rate and direction of the groundwater flow by a number of processes.

SECONDARY YMP FEP NUMBER: 2.2.11.03.03
FEP NAME: Gas Mediated Transport

ORIGINATOR FEP DESCRIPTION: None.

SECONDARY YMP FEP NUMBER: 2.2.11.03.04
FEP NAME: Far-field transport: Transport of radioactive gases

ORIGINATOR FEP DESCRIPTION: Certain gaseous or volatile radionuclides may be able to migrate through the far-field faster than the groundwater advection rate.

SECONDARY YMP FEP NUMBER: 2.2.11.03.05
FEP NAME: Gas discharge

ORIGINATOR FEP DESCRIPTION: Some radionuclides migrating through the far-field may do so in the gas phase, e.g. tritium or 14-C in carbon dioxide or methane. Transfer of gaseous radionuclides from the far-field to the biosphere is likely to occur at specific 'entry' points to the biosphere controlled by faults or fractures.

SECONDARY YMP FEP NUMBER: 2.2.11.03.06
FEP NAME: Transport of radioactive gases

ORIGINATOR FEP DESCRIPTION: The production and potential transport of radioactive gases is discussed under FEP W2.055, where they are eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal

ATTACHMENT VII

SEISMIC/IGNEOUS/ROCK CHARACTERISTICS FEPS DESCRIPTIONS

PRIMARY YMP FEP NUMBER: 1.2.02.01.00
FEP NAME: Fractures

ORIGINATOR FEP DESCRIPTION: (Identified as "Formation of fractures' by originator) Groundwater flow in the region of the WIPP and transport of any released radionuclides may take place along fractures. The rate of flow and the extent of transport will be influenced by fracture characteristics such as orientation, aperture, asperity, fracture length and connectivity, and the nature of any linings or infills. These characteristics are accounted for in the performance assessment calculations through the description of the hydrogeological properties of the transmissive units.

YMP PRIMARY FEP DESCRIPTION: Groundwater flow in the Yucca Mountain region and transport of any released radionuclides may take place along fractures. Transmissive fractures may be existing, reactivated, or newly formed fractures. The rate of flow and the extent of transport in fractures is influenced by characteristics such as orientation, aperture, asperity, fracture length, connectivity, and the nature of any linings or infills. Generation of new fractures and reactivation of preexisting fractures may significantly change the flow and transport paths. Newly formed and reactivated fractures typically result from thermal, seismic, or tectonic events.

SECONDARY YMP FEP NUMBER: 1.2.02.01.01
FEP NAME: Changes in fracture properties

ORIGINATOR FEP DESCRIPTION: Groundwater flow in the region of the WIPP and transport of any released radionuclides may take place along fractures. The rate of flow and the extent of transport will be influenced by fracture characteristics such as orientation, aperture, asperity, fracture length and connectivity, and the nature of any linings or infills. etc.

SECONDARY YMP FEP NUMBER: 1.2.02.01.02
FEP NAME: Fracturing

ORIGINATOR FEP DESCRIPTION: None.

ORIGINATOR FEP DESCRIPTION: Exit from individual glacial periods will cause large volumes of surface water to accumulate as some glaciers melt. Melt water, and its rate of production, have an important effect on surface environments, groundwater fluxes and flow directions.

PRIMARY YMP FEP NUMBER: 1.2.02.02.00
FEP NAME: Faulting

ORIGINATOR FEP DESCRIPTION: Faulting may occur due to sudden major changes in the stress situation, e.g. earthquakes etc., and due to slow motions (creep) in the rock mass, e.g. orogenic events, loading-unloading of an ice-load, and plate motions. The result of the release of stress may be the formation of a fracture, and if movement occurs along the fracture, a fault. A more likely event is movement along already existing fractures and faults.

Faulting may alter the rock permeability in the rock mass and alter or short-circuit the flow paths and flow distributions close to the repository and create new pathways through the repository. New or regenerated faults may enhance the groundwater flow, destabilise and damage engineered barriers, thus decreasing the transport times for potentially released radionuclides. etc.

YMP PRIMARY FEP DESCRIPTION: Faulting may occur due to sudden major changes in the stress situation (e.g. seismic activity) or due to slow motions in the rock mass (e.g., tectonic activity). Movement along existing fractures and faults is more likely than the formation of new faults. Faulting may alter the rock permeability in the rock mass and alter or short-circuit the flow paths and flow distributions close to the repository and create new pathways through the repository. New faults or the Cavitation of existing faults may enhance the groundwater flow, thus decreasing the transport times for potentially released radionuclides.

SECONDARY YMP FEP NUMBER: 1.2.02.02.01
FEP NAME: Faulting

ORIGINATOR FEP DESCRIPTION: Movement between adjacent rock masses, along a fracture, could result in changes hydraulic heads, groundwater flow and rock stresses.

SECONDARY YMP FEP NUMBER: 1.2.02.02.02
FEP NAME: Fault generation

ORIGINATOR FEP DESCRIPTION: None.

SECONDARY YMP FEP NUMBER: 1.2.02.02.03
FEP NAME: Fault activation

ORIGINATOR FEP DESCRIPTION: None.

SECONDARY YMP FEP NUMBER: 1.2.02.02.04
FEP NAME: Movements along small-scale faults

ORIGINATOR FEP DESCRIPTION: A fraction of the deformation will be absorbed by minor faults such as the cataclastic zones intercepting emplacement tunnels. The displacement is likely to be the order of a few centimeters and not exceed 1 m in one million years. etc.

SECONDARY YMP FEP NUMBER: 1.2.02.02.05
FEP NAME: Faulting/fracturing

ORIGINATOR FEP DESCRIPTION: Faults and fractures are the primary pathway for groundwater movement and, hence, radionuclide transport. Generation of new faults and reactivation of preexisting faults may significantly change the far-field transport paths.

SECONDARY YMP FEP NUMBER: 1.2.02.02.06
FEP NAME: Formation of new faults

ORIGINATOR FEP DESCRIPTION: Faults are present in the Delaware Basin in both the units underlying the Salado and in the Permian evaporite sequence. According to Powers et al (1978,4-57), there is evidence that movement along faults within the pre Permian units affected the thickness of Early Permian strata, but these faults did not exert a structural control on the deposition of the Castile, the Salado, or the Rustler. etc.

SECONDARY YMP FEP NUMBER: 1.2.02.02.07
FEP NAME: Fault movement

ORIGINATOR FEP DESCRIPTION: Faults are present in the Delaware Basin in both the units underlying the Salado and in the Permian evaporite sequence. According to Powers et al (1978,4-57), there is evidence that movement along faults within the pre-Permian units affected the thickness of Early Permian strata, but these faults did not exert a structural control on the deposition of the Castile, the Salado, or the Rustler. etc.

SECONDARY YMP FEP NUMBER: 1.2.02.02.08
FEP NAME: Normal faulting occurs or exists at Yucca Mountain

ORIGINATOR FEP DESCRIPTION: Normal faulting occurs around Yucca Mtn or normal movement on existing normal faults occurs.

SECONDARY YMP FEP NUMBER: 1.2.02.02.09
FEP NAME: Strike/slip faulting occurs or exists at Yucca Mountain

ORIGINATOR FEP DESCRIPTION: Strike/slip faulting occurs around Yucca Mtn or strike/slip movement on existing faults occurs.

SECONDARY YMP FEP NUMBER: 1.2.02.02.10
FEP NAME: Detachment faulting occurs or exists at Yucca Mountain

ORIGINATOR FEP DESCRIPTION: Detachment faulting occurs around Yucca Mtn or movement on existing listric faults occurs.

SECONDARY YMP FEP NUMBER: 1.2.02.02.11
FEP NAME: Dip/slip faulting occurs at Yucca Mountain

ORIGINATOR FEP DESCRIPTION: Dip/slip faulting occurs around Yucca Mtn or dip/slip movement on existing faults occurs.

SECONDARY YMP FEP NUMBER: 1.2.02.02.12
FEP NAME: New fault occurs at Yucca Mountain

ORIGINATOR FEP DESCRIPTION: A new fault develops through or near Yucca Mountain.

SECONDARY YMP FEP NUMBER: 1.2.02.02.13
FEP NAME: Old fault strand is reactivated at Yucca Mountain

ORIGINATOR FEP DESCRIPTION: An old fault strand (e.g. H-5 Splay of Solitario Canyon fault) through or near Yucca Mountain is reactivated.

SECONDARY YMP FEP NUMBER: 1.2.02.02.14
FEP NAME: New fault strand is activated at Yucca Mountain

ORIGINATOR FEP DESCRIPTION: A new fault strand develops from an existing fault through or near Yucca Mountain (e.g. a strand off Solitario Canyon fault, in the manner of the H-5 Splay).

SECONDARY YMP FEP NUMBER: 1.2.02.02.15
FEP NAME: Movements along major faults

ORIGINATOR FEP DESCRIPTION: Movements along faults will occur due to the updoming of the Southern Black Forest and the existing compressive stress field in the crystalline basement resulting from the Alpine orogeny. The relative movement along any fault will lie in the range 0 to 100 m in one million years.

SECONDARY YMP FEP NUMBER: 1.2.02.02.16
FEP NAME: Faulting (large scale, in geosphere)

ORIGINATOR FEP DESCRIPTION: Faulting may occur due to sudden changes in the stress situation, e.g. earthquakes, etc., and due to slow motions (creep) in the rockmass,e.g. orogenic events, loading-unloading of an ice load, and plate motions. The result is a fracture or if a movement occurs along the fracture, a fault.

SECONDARY YMP FEP NUMBER: 1.2.02.02.17
FEP NAME: Faulting (large scale, in geosphere)

ORIGINATOR FEP DESCRIPTION: Faulting may occur due to sudden changes in the stress situation, e.g. earthquakes, etc., and due to slow motions (creep) in the rockmass,e.g. orogenic events, loading-unloading of an ice load, and plate motions. The result is a fracture or if a movement occurs along the fracture, a fault.

PRIMARY YMP FEP NUMBER: 1.2.03.01.00
FEP NAME: Seismic activity

ORIGINATOR FEP DESCRIPTION: (Identified as "Earthquakes" by originator)
Earthquakes could produce jointed-rock motion, rapid fault growth, slow fault growth or new fault formation, resulting in changes in hydraulic heads, changes in groundwater recharge or discharge zones, changes in rock stresses and severe disruption of the integrity of the vault.

YMP PRIMARY FEP DESCRIPTION: Seismic activity (i.e., earthquakes) could produce jointed-rock motion, rapid fault growth, slow fault growth or new fault formation, resulting in changes in hydraulic heads, changes in groundwater recharge or discharge zones, changes in rock stresses, and severe disruption of the integrity of the drifts (e.g., vibration damage, rockfall).

SECONDARY YMP FEP NUMBER: 1.2.03.01.01
FEP NAME: Earthquakes

ORIGINATOR FEP DESCRIPTION: Large earthquakes, vibration from many smaller earthquakes or related events such as movement of the crust or plate could affect all components of the vault.

SECONDARY YMP FEP NUMBER: 1.2.03.01.02
FEP NAME: Earthquakes

ORIGINATOR FEP DESCRIPTION: Earthquakes could influence the containment of the nuclear fuel waste by opening or closing fractures in the geosphere. This may change the discharge of contaminants from the geosphere into the biosphere.

SECONDARY YMP FEP NUMBER: 1.2.03.01.03
FEP NAME: Earthquakes

ORIGINATOR FEP DESCRIPTION: Earthquakes occur in Sweden. They are usually small, magnitude 0-4, but there are historic examples with earthquakes up to magnitude 6. etc.

SECONDARY YMP FEP NUMBER: 1.2.03.01.04
FEP NAME: Seismicity

ORIGINATOR FEP DESCRIPTION: None.

SECONDARY YMP FEP NUMBER: 1.2.03.01.05
FEP NAME: Seismicity

ORIGINATOR FEP DESCRIPTION: Seismic activity is low in the potential repository siting areas in Northern Switzerland and the corresponding risk to safety is considered negligible. Direct disturbance of a sealed repository by seismic activity can practically be ruled out. etc.

SECONDARY YMP FEP NUMBER: 1.2.03.01.06
FEP NAME: Seismicity

ORIGINATOR FEP DESCRIPTION: Seismicity is the compressional and shear wave energy transmitted through the rock mass resulting naturally from the generation or reactivation of faults; it may also be induced due to stress-relief mechanisms in the near-field.

SECONDARY YMP FEP NUMBER: 1.2.03.01.07
FEP NAME: Seismic activity

ORIGINATOR FEP DESCRIPTION: This FEP is concerned with the effects of seismic activity away from the immediate source region, and only the effects of groundshine and earthquakes are discussed.

PRIMARY YMP FEP NUMBER: 1.2.04.02.00
FEP NAME: Igneous activity causes changes to rock properties

ORIGINATOR FEP DESCRIPTION: (Identified as "Igneous activity causes extreme changes to rock hydrologic properties" by originator)
Igneous activity near the underground facility causes extreme changes to rock hydrologic properties. Permeabilities of dikes and sills and the heated regions immediately around them can differ from those of country rock.

YMP PRIMARY FEP DESCRIPTION: Igneous activity near the underground facility causes extreme changes to rock hydrologic and mineralogic properties. Permeabilities of dikes and sills and the heated regions immediately around them can differ from those of country rock. Mineral alterations can also change the chemical response to contaminants.

SECONDARY YMP FEP NUMBER: 1.2.04.02.01
FEP NAME: Dike provides a permeable flow path

ORIGINATOR FEP DESCRIPTION: A new dike develops well-connected cooling fractures and is more permeable than the surrounding rock.

SECONDARY YMP FEP NUMBER: 1.2.04.02.02
FEP NAME: Dike provides a barrier to flow

ORIGINATOR FEP DESCRIPTION: A new dike is less permeable than the surrounding rock.

SECONDARY YMP FEP NUMBER: 1.2.04.02.03
FEP NAME: Volcanic activity in the vicinity produces an impoundment

ORIGINATOR FEP DESCRIPTION: Volcanic activity in the vicinity of the site (e.g., lava flow) leads to damming of a wash or canyon that produces a large surface-water impoundment. Percolation flux is substantially increased beneath the impoundment and interacts with the repository.

SECONDARY YMP FEP NUMBER: 1.2.04.02.04
FEP NAME: Igneous activity causes extreme changes to rock geochemical properties

ORIGINATOR FEP DESCRIPTION: Igneous activity near the underground facility causes extreme changes to rock mineralogic properties. Mineral alterations also change the chemical response to contaminants.

SECONDARY YMP FEP NUMBER: 1.2.04.02.05
FEP NAME: Intrusion (magmatic)

ORIGINATOR FEP DESCRIPTION: Magmatism near the disposal facility could lead to substantial changes in existing groundwater flows and rock properties.

SECONDARY YMP FEP NUMBER: 1.2.04.02.06
FEP NAME: Dike related fractures alter flow

ORIGINATOR FEP DESCRIPTION: The intrusion, either by emplacement or during cooling can produce a set of fractures in a zone adjacent to the dike, altering flow characteristics.

SECONDARY YMP FEP NUMBER: 1.2.04.02.07
FEP NAME: Magmatic activity

ORIGINATOR FEP DESCRIPTION: Magmatism could occur in the vicinity of the vault, leading to substantial changes to groundwater flow and rock properties.

PRIMARY YMP FEP NUMBER: 1.2.06.00.00
FEP NAME: Hydrothermal activity

ORIGINATOR FEP DESCRIPTION: Hydrothermal activity refers to FEPs associated with high temperature groundwaters, including processes such as density-driven groundwater flow and hydrothermal alteration of minerals in the rocks through which the high temperature groundwater flows.

YMP PRIMARY FEP DESCRIPTION: This category contains FEPs associated with naturally-occurring high-temperature groundwaters, including processes such as density-driven groundwater flow and hydrothermal alteration of minerals in the rocks through which the high temperature groundwater flows.

SECONDARY YMP FEP NUMBER: 1.2.06.00.01
FEP NAME: Hydrothermal activity

ORIGINATOR FEP DESCRIPTION: A relationship between the increased geothermal gradient in Northern Switzerland and the Permo-Carboniferous Trough has been postulated on several occasions. The fault system at the margin of the trough appear to promote the rise of groundwaters. etc.

PRIMARY YMP FEP NUMBER: 1.2.10.01.00
FEP NAME: Hydrological response to seismic activity

ORIGINATOR FEP DESCRIPTION: (Identified as "Hydrological response to earthquakes" by originator)
There are a variety of hydrological responses to earthquakes. Some of these responses, such as changes to surface-water flow directions, result directly from fault movement. Others, such as changes in subsurface water chemistry and temperature, probably result from changes in flow pathways along the fault or fault zone. etc.

YMP PRIMARY FEP DESCRIPTION: Seismic activity, associated with fault movement, may create new or enhanced flow pathways and/or connections between stratigraphic units, or it may change the stress (and therefore fluid pressure) within the rock. These responses have the potential to significantly change the surface- and groundwater flow directions, water level, water chemistry and temperature.

SECONDARY YMP FEP NUMBER: 1.2.10.01.01
FEP NAME: Fault movement pumps fluid from SZ to UZ (seismic pumping)

ORIGINATOR FEP DESCRIPTION: Fault movement relieves stress (increased fluid pressure in pores and fractures) in the saturated zone by driving water up fractures in the unsaturated zone, thus raising the water table.

SECONDARY YMP FEP NUMBER: 1.2.10.01.02
FEP NAME: Fault creep causes short term fluctuations of the water table

ORIGINATOR FEP DESCRIPTION: Fault creep includes minor restructuring of the in situ strain-energy field. This change causes short-term stress-induced fluctuations in the level of the water table.

SECONDARY YMP FEP NUMBER: 1.2.10.01.03
FEP NAME: New faulting breaches flow barrier controlling large hydraulic gradient to the north

ORIGINATOR FEP DESCRIPTION: Fracturing along a new fault creates a permeable pathway through the flow barrier assumed to control the large hydraulic gradient and the water table rises to the top of the Calico Hills unit.

SECONDARY YMP FEP NUMBER: 1.2.10.01.04
FEP NAME: Normal faulting produces a trap for laterally moving moisture in the Tiva Canyon unit

ORIGINATOR FEP DESCRIPTION: Normal faulting produces a trap intercepting laterally moving moisture in the Tiva Canyon unit and increases flux in the Topopah Spring units.

SECONDARY YMP FEP NUMBER: 1.2.10.01.05
FEP NAME: Head-driven flow up from Carbonates

ORIGINATOR FEP DESCRIPTION: A fault connection of the EBS, UZ, and SZ allows water flow up the fault from the carbonates to the EBS.

SECONDARY YMP FEP NUMBER: 1.2.10.01.06
FEP NAME: Seismically-induced water table changes

ORIGINATOR FEP DESCRIPTION: As a result of distant earthquakes, the local water table elevation changes.

SECONDARY YMP FEP NUMBER: 1.2.10.01.07
FEP NAME: Fault pathway through the altered Topopah Spring basal vitrophyre

ORIGINATOR FEP DESCRIPTION: Movement along an old fault or creation of a new fault generates a pathway thru the altered Topopah Spring basal vitrophyre.

SECONDARY YMP FEP NUMBER: 1.2.10.01.08
FEP NAME: Fault movement connects tuff and carbonate aquifers

ORIGINATOR FEP DESCRIPTION: A new fault or movement on an old fault establishes a connection between the tuff aquifers and the carbonate aquifers.

SECONDARY YMP FEP NUMBER: 1.2.10.01.09
FEP NAME: Fault establishes pathway through the UZ

ORIGINATOR FEP DESCRIPTION: Movement along an old fault or creation of a new fault generates a pathway thru the UZ.
SECONDARY YMP FEP NUMBER: 1.2.10.01.10
FEP NAME: Fault establishes pathway through the SZ

ORIGINATOR FEP DESCRIPTION: Movement along an old fault or creation of a new fault generates a flow path in the SZ.

SECONDARY YMP FEP NUMBER: 1.2.10.01.11
FEP NAME: Fluid supplied by a fault migrates down the drift

ORIGINATOR FEP DESCRIPTION: A pathway established by fault movement through the repository brings fluid to the drift; fluid which migrates down the drift to transport contaminants down other pathways in the UZ.

SECONDARY YMP FEP NUMBER: 1.2.10.01.12
FEP NAME: Fault intersects and drains condensate zone

ORIGINATOR FEP DESCRIPTION: Movement on a fault (new or old) intersects a condensate zone above the drifts and the fault drains the condensate into one or more drifts.

SECONDARY YMP FEP NUMBER: 1.2.10.01.13
FEP NAME: Flow barrier south of site blocks flow, causing water table to rise

ORIGINATOR FEP DESCRIPTION: As in YSCP15, fault-caused fracturing breaches the flow barrier north of the repository block. Flow is blocked by another barrier, not apparent from the current head distribution, and the resulting rise in water table floods the repository. Water passing through the repository discharges through springs in Forty mile Wash.

PRIMARY YMP FEP NUMBER: 1.2.10.02.00
FEP NAME: Hydrologic response to igneous activity

ORIGINATOR FEP DESCRIPTION: (Identified as "Igneous intrusion causes water table to rise" by originator) An igneous intrusion produces a barrier to flow or drastically alters thermal conditions, causing the water table to rise.

YMP PRIMARY FEP DESCRIPTION: Igneous activity may change the groundwater flow directions, water level, water chemistry and temperature. Igneous activity includes magmatic intrusions which may change rock properties and flow pathways, and thermal effects which may heat up groundwater and rock.

SECONDARY YMP FEP NUMBER: 1.2.10.02.01
FEP NAME: Interaction of WT with Magma

ORIGINATOR FEP DESCRIPTION: None.

SECONDARY YMP FEP NUMBER: 1.2.10.02.02
FEP NAME: Interaction of UZ Pore Water with Magma

ORIGINATOR FEP DESCRIPTION: Issues: heating, steam explosions.

PRIMARY YMP FEP NUMBER: 2.2.06.02.00
FEP NAME: Changes in stress (due to thermal, seismic, or tectonic effects) produce change in permeability of faults

ORIGINATOR FEP DESCRIPTION: (Identified as "Alteration of permeability along and across faults due to changes in stress" by originator. Stress changes due to tectonic and seismic events alter the permeability along and across faults.

YMP PRIMARY FEP DESCRIPTION: Stress changes due to thermal, tectonic and seismic processes result in strains that alter the permeability along and across faults.

SECONDARY YMP FEP NUMBER: 2.2.06.02.01
FEP NAME: Aseismic alteration of permeability along and across fault

ORIGINATOR FEP DESCRIPTION: Aseismic stress changes due to tectonic events alter the permeability along and across faults.

SECONDARY YMP FEP NUMBER: 2.2.06.02.02
FEP NAME: Fracture dilation along faults creates zones of enhanced permeability

ORIGINATOR FEP DESCRIPTION: Fracture dilation along faults creates zones of enhanced permeability in the Calico Hills and Paintbrush nonwelded units. Erosion of an arroyo at the surface and increased hydraulic conductivity of the Paintbrush unit create a zone of increased percolation along the fault. Moisture moves through fractures along the fault.

SECONDARY YMP FEP NUMBER: 2.2.06.02.03
FEP NAME: Relaxation of thermal stresses by fault movement

ORIGINATOR FEP DESCRIPTION: Thermo-mechanical stress buildup in the mountain may produce movement on adjacent faults.

SECONDARY YMP FEP NUMBER: 2.2.06.02.04
FEP NAME: Seismically-stimulated release of thermo-mechanical stress on bounding fault

ORIGINATOR FEP DESCRIPTION: Thermo-mechanical stress accumulated as a result of repository heat is stimulated by seismic waves to be released on nearby faults.

SECONDARY YMP FEP NUMBER: 2.2.06.02.05
FEP NAME: Relaxation of thermal stresses by fault movement

ORIGINATOR FEP DESCRIPTION: Thermo-mechanical stress buildup in the mountain may produce movement on adjacent faults.

PRIMARY YMP FEP NUMBER: 2.2.06.03.00
FEP NAME: Changes in stress (due to seismic or tectonic effects) alter perched water zones

ORIGINATOR FEP DESCRIPTION: Identified as "Stress changes alter water budget of perched zones" by originator. Strain due to stress changes from tectonic and seismic events alter the permeabilities which allow formation of perched water zones.

YMP PRIMARY FEP DESCRIPTION: Strain caused by stress changes from tectonic or seismic events alters the rock permeabilities that allow formation and persistence of perched water zones.

SECONDARY YMP FEP NUMBER: 2.2.06.03.01
FEP NAME: Perched zones develop as a result of stress changes

ORIGINATOR FEP DESCRIPTION: Strain due to stress changes from tectonic and seismic events alter the permeabilities and allow development of perched water zones.

PRIMARY YMP FEP NUMBER: 2.2.12.00.00
FEP NAME: Undetected features (in geosphere)

ORIGINATOR FEP DESCRIPTION: Undetected features refers to FEPs related to natural or man-made features within the geology that may not be detected during the site investigation.

YMP PRIMARY FEP DESCRIPTION: This category contains FEPs related to undetected features in the geosphere that can affect long-term performance of the disposal system. Undetected but important features may be present, and have significant impacts. These features include unknown active fracture zones, inhomogeneities, faults and features connecting different zones of rock, different geometries for fracture zones and induced fractures due to the construction or presence of the repository.

SECONDARY YMP FEP NUMBER: 2.2.12.00.01
FEP NAME: Undetected dike beneath the repository passing thru the Calico Hills provides a highly permeable flow path

ORIGINATOR FEP DESCRIPTION: An undetected dike passing through the Calico Hills nonwelded unit below the repository has a high fracture permeability and provides a rapid flow path.

SECONDARY YMP FEP NUMBER: 2.2.12.00.02
FEP NAME: Undetected fault dips below the repository providing a highly permeable flow path

ORIGINATOR FEP DESCRIPTION: An undetected major fault dips below the repository. The fault has greater permeability than surrounding unfaulted rock, and enhanced moisture flow along it passes through the Calico Hills nonwelded unit in fractures.

SECONDARY YMP FEP NUMBER: 2.2.12.00.03
FEP NAME: Undetected fault beneath the repository acts as a flow barrier altering the flow system

ORIGINATOR FEP DESCRIPTION: An undetected major fault dips below the repository. Because of the formation of fault gouge, matrix hydraulic conductivity in the fault is less than the moisture flux, and so moisture flows through the Calico Hills nonwelded unit along fractures in or just above the fault.

SECONDARY YMP FEP NUMBER: 2.2.12.00.04
FEP NAME: Undetected fault connects tuff aquifers to carbonate aquifers; providing a fast path

ORIGINATOR FEP DESCRIPTION: An undetected fault provides a path for water movement from the tuff aquifer beneath the western portion of the repository to an underlying carbonate aquifer.

SECONDARY YMP FEP NUMBER: 2.2.12.00.05
FEP NAME: *Perched water escapes detection and waste is put in it*

ORIGINATOR FEP DESCRIPTION: A wet zone below a minor fault through the Tiva Canyon lower contact escapes detection during the repository construction, and waste is emplaced in it..

SECONDARY YMP FEP NUMBER: 2.2.12.00.06
FEP NAME: *Undiscovered mine shaft (an old prospect hole) in a wash acts as a source for increased local infiltration*

ORIGINATOR FEP DESCRIPTION: An old prospect in a wash retains water after floods and therefore is a source of enhanced infiltration. The wet zone beneath is not detected during repository construction, and waste is emplaced in it.

SECONDARY YMP FEP NUMBER: 2.2.12.00.07
FEP NAME: *Rock properties-undetected features*

ORIGINATOR FEP DESCRIPTION: Undetected but important features may be present, and have significant impacts. These features include unknown active fracture zones, inhomogeneities, faults and features connecting different zones of rock, different geometries for fracture zones and induced fractures due to the construction or presence of the vault.

SECONDARY YMP FEP NUMBER: 2.2.12.00.08
FEP NAME: *Undetected fracture zone*

ORIGINATOR FEP DESCRIPTION: Fracture zones are part of our conceptual model. It is not clear that possibly undetected features are dealt with in the "standard" sensitivity/uncertainty analysis. Undetected features can be analyzed by using the frequency of fracture zones from other sites.

SECONDARY YMP FEP NUMBER: 2.2.12.00.09
FEP NAME: *Undetected features*

ORIGINATOR FEP DESCRIPTION: None.

SECONDARY YMP FEP NUMBER: 2.2.12.00.10
FEP NAME: *Undetected past intrusions*

ORIGINATOR FEP DESCRIPTION: None.

SECONDARY YMP FEP NUMBER: *2.2.12.00.11*
FEP NAME: *Undetected discontinuities (in geosphere)*

ORIGINATOR FEP DESCRIPTION: Undetected discontinuities in the geosphere may affect performance.

ATTACHMENT VIII

REPOSITORY PERTURBED THMC FEPS DESCRIPTIONS

PRIMARY YMP FEP NUMBER: 1.1.02.00.00
FEP NAME: Excavation/construction

ORIGINATOR FEP DESCRIPTION: Excavation/construction refers to FEPs related to the excavation of shafts, tunnels, disposal galleries, silos etc. of a repository, the stabilization of these openings and installation/assembly of structural elements.

YMP PRIMARY FEP DESCRIPTION: This category contains FEPs related to the excavation of the underground regions of the repository, and effects of this excavation on the long-term behavior of the engineered and natural barriers. Excavation-related effects include changes to rock properties due to boring and blasting and geochemical changes to rock and groundwater.

SECONDARY YMP FEP NUMBER: 1.1.02.00.01
FEP NAME: Blasting and vibration

ORIGINATOR FEP DESCRIPTION: Blasting and vibration during construction of the vault (or afterwards) could substantially alter rock properties and water flow fields.

SECONDARY YMP FEP NUMBER: 1.1.02.00.02
FEP NAME: Geochemical alteration (excavation)

ORIGINATOR FEP DESCRIPTION: Various geochemical alterations may occur during the desaturation and resaturation phases associated with excavation and backfilling in the EDZ. These are assumed to be insignificant in the assessment.

SECONDARY YMP FEP NUMBER: 1.1.02.00.03
FEP NAME: Groundwater chemistry (excavation)

ORIGINATOR FEP DESCRIPTION: Various changes will occur in the porewater chemistry during the desaturation and resaturation phases associated with excavation, open period and backfilling. At present, no special assumptions are made for the composition of the EDZ groundwater.

SECONDARY YMP FEP NUMBER: 1.1.02.00.04
FEP NAME: Influx of oxidizing water

ORIGINATOR FEP DESCRIPTION: Influx of oxidizing water through water-conducting features during the construction phase would alter their hydrochemistry and mineralogy. This is unlikely since groundwaters in the HPD and MWCF are also reducing.

SECONDARY YMP FEP NUMBER: 1.1.02.00.05
FEP NAME: Influx of oxidizing water

ORIGINATOR FEP DESCRIPTION: Influx of oxidizing water through water-conducting features during the construction phase would alter their hydrochemistry and mineralogy. This is unlikely since groundwaters in the HPD and MWCF are also reducing.

PRIMARY YMP FEP NUMBER: 2.2.01.01.00
FEP NAME: Excavation and construction-related changes in the adjacent host rock

ORIGINATOR FEP DESCRIPTION: Identified as "Excavation-disturbed zone (EDZ)" by the originator. During tunnel and shaft construction, some stress relief, leading to dilation of joints and fractures, is expected in an axial zone of up to one diameter width surrounding the tunnels and shaft; this is termed the excavation-disturbed zone (EDZ). The characteristics and long-term importance of this zone are uncertain. etc.

YMP PRIMARY FEP DESCRIPTION: Excavation will produce some disturbance of the rocks surrounding the drifts due to stress relief. Stresses associated directly with excavation (e.g., boring and blasting operations) may also cause some changes in rock properties. Properties that may be affected include rock strength, fracture spacing and block size, and hydrologic properties such as permeability.

SECONDARY YMP FEP NUMBER: 2.2.01.01.01
FEP NAME: Disturbed rock zone

ORIGINATOR FEP DESCRIPTION: Construction of the repository has caused local excavation-induced changes in stress in the surrounding rock. This has led to failure of intact rock around the opening, creating a disturbed rock zone of fractures. etc.

SECONDARY YMP FEP NUMBER: 2.2.01.01.02
FEP NAME: Mechanical effects - Excavation/backfilling effects

ORIGINATOR FEP DESCRIPTION: This FEP is redundant in the NEA database with J4.2.02.1 (entered in this database as 2.2.01e), and is retained here for completeness.

SECONDARY YMP FEP NUMBER: 2.2.01.01.03
FEP NAME: Formation of cracks (host rock disturbed zone)

ORIGINATOR FEP DESCRIPTION: Cracks and faults could form or exist within or near the vault, affecting the performance of seals, grouts and the buffer.

SECONDARY YMP FEP NUMBER: 2.2.01.01.04
FEP NAME: Damaged zone (host rock disturbed zone)

ORIGINATOR FEP DESCRIPTION: Enhanced groundwater flow and contaminant transport could occur within the zone of rock surrounding the shafts and vault that has been damaged during blasting or excavation.

SECONDARY YMP FEP NUMBER: 2.2.01.01.05
FEP NAME: Excavation/backfilling effects on nearby rock

ORIGINATOR FEP DESCRIPTION: A potentially serious complicating factor for flow in crystalline rock is that the rock is deformable. Even small changes in the fracture openings cause large changes in permeability as the permeability is proportional to the aperture cubed. etc.

SECONDARY YMP FEP NUMBER: 2.2.01.01.06
FEP NAME: Mechanical effects - Excavation/backfilling effects

ORIGINATOR FEP DESCRIPTION: This FEP is treated in Excavation/backfilling on nearby rock J4.2.2.1.

SECONDARY YMP FEP NUMBER: 2.2.01.01.07
FEP NAME: Enhanced rock fracturing

ORIGINATOR FEP DESCRIPTION: Enhanced rock fracturing may be caused by excavation of repository through blasting and stress redistribution.

SECONDARY YMP FEP NUMBER: 2.2.01.01.08
FEP NAME: Creeping of rock mass, near-field

ORIGINATOR FEP DESCRIPTION: Creeping of rock mass occur in connection with excavation due to stress changes. These changes create an unstable situation in the rock mass close to the repository. However, this effect is probably of minor importance.

SECONDARY YMP FEP NUMBER: 2.2.01.01.09
FEP NAME: Excavation effects on nearby rock

ORIGINATOR FEP DESCRIPTION: Excavating a repository in hard crystalline rock implies that there will be a volume of the rock that will be affected by the excavation, operation and sealing. The rock mass will be disturbed, it will be altered in an immediate and possibly time dependent way due to the excavation process (e.g. drilling, blasting) and by the stress redistribution resulting from removal of constraint around the system.

SECONDARY YMP FEP NUMBER: 2.2.01.01.10
FEP NAME: Disturbed zone (hydromechanical) effects

ORIGINATOR FEP DESCRIPTION: The disturbed zone formed around the repository during construction may change the local hydrogeological system around the disposal vaults and access excavations.

SECONDARY YMP FEP NUMBER: 2.2.01.01.11
FEP NAME: Excavation-induced changes in stress

ORIGINATOR FEP DESCRIPTION: Construction of the repository has caused local excavation-induced changes in stress in the surrounding rock. This has led to failure of intact rock around the opening, creating a disturbed rock zone of fractures. etc.

PRIMARY YMP FEP NUMBER: 2.2.01.05.00
FEP NAME: Radionuclide transport in excavation disturbed zone

ORIGINATOR FEP DESCRIPTION: Identified as "Radionuclide migration (excavation disturbed zone)" by originator. Radionuclides emerging from the backfill can move advectively in open fissures in the decompressed zones, to reach the flow systems in the host rock. ... In assessment calculations, immediate transport from the bentonite periphery to water-conducting features in the host rock is assumed.

YMP PRIMARY FEP DESCRIPTION: Radionuclide transport through the excavation disturbed zone may differ from transport in the waste and EBS and the undisturbed host rock. Transport processes such as dissolution and precipitation, sorption, and colloid filtration should be considered.

SECONDARY YMP FEP NUMBER: 2.2.01.05.01
FEP NAME: Radionuclide retardation (excavation-disturbed zone)

ORIGINATOR FEP DESCRIPTION: Radionuclides transported from the bentonite through the EDZ to the far-field flow system may be retarded by sorption and matrix diffusion.

SECONDARY YMP FEP NUMBER: 2.2.01.05.02
FEP NAME: Radionuclide release from EDZ

ORIGINATOR FEP DESCRIPTION: The radionuclides diffusing from the bentonite buffer to the EDZ are assumed to be transported immediately to transmissive elements in the host rock. The total release from the EDZ is taken to be the release from a single canister calculated by the STRENG model multiplied by the total number of canisters.

PRIMARY YMP FEP NUMBER: 2.2.07.10.00
FEP NAME: Condensation zone forms around drifts

ORIGINATOR FEP DESCRIPTION: Condensation of the 2-phase flow generated by repository heat forms in the rock where the temperature drops below the local vaporization temperature.

YMP PRIMARY FEP DESCRIPTION: Condensation of the 2-phase flow generated by repository heat forms in the rock where the temperature drops below the local vaporization temperature. Waste package emplacement geometry and thermal loading will affect the scale at which condensation caps form (over waste packages, over panels, or over the entire repository), and the extent to which "shedding" will occur as water flows from the region above one drift to the region above another drift or into the rock between drifts.

SECONDARY YMP FEP NUMBER: 2.2.07.10.01
FEP NAME: Condensation cap forms above repository

ORIGINATOR FEP DESCRIPTION: Water accumulates above the repository during the thermal period due to the "thermal barrier" created by evaporation and precipitation.

SECONDARY YMP FEP NUMBER: 2.2.07.10.02
FEP NAME: Formation of condensate over individual containers

ORIGINATOR FEP DESCRIPTION: Condensate formed in the rock above the drift over individual containers.

SECONDARY YMP FEP NUMBER: 2.2.07.10.03
FEP NAME: Formation of condensate over individual panels

ORIGINATOR FEP DESCRIPTION: Condensate formed in the rock above the drift over individual waste emplacement panels.

SECONDARY YMP FEP NUMBER: 2.2.07.10.04
FEP NAME: Formation of condensate over the entire repository

ORIGINATOR FEP DESCRIPTION: Condensate formed in the rock above the drift over individual waste emplacement panels.

SECONDARY YMP FEP NUMBER: 2.2.07.10.05
FEP NAME: Shedding of condensation cap over one drift to another drift

ORIGINATOR FEP DESCRIPTION: A condensate zone which forms over one drift during the thermal period, is redirected or shed to another adjacent drift.

SECONDARY YMP FEP NUMBER: 2.2.07.10.06
FEP NAME: Vault geometry

ORIGINATOR FEP DESCRIPTION: Effects deriving from the complex 3-dimensional geometry of the vault may be important.

PRIMARY YMP FEP NUMBER: 2.2.07.11.00
FEP NAME: Return flow from condensation cap / resaturation of dry-out zone

ORIGINATOR FEP DESCRIPTION: During the thermal period, a condensation zone forms above the drifts - a condensation cap. When the rocks have cooled enough, there is a return flow toward the drifts from the condensation cap as a plume of unsaturated flow.

YMP PRIMARY FEP DESCRIPTION: Following the peak thermal period, water in the condensation cap (see FEP 2.2.07.10.00) may flow downward into the drifts. Influx of cooler water from above, such as might occur from episodic flow, may accelerate return flow from the condensation cap by lowering temperatures below the condensation point. Percolating groundwater (distinct from water mobilized from the condensation cap) will also contribute to resaturation of the dry out zone. Vapor flow, as distinct from liquid flow by capillary processes, may also contribute. Water chemistry in the resaturation period may be affected by processes in the condensation cap and dry-out zone.

SECONDARY YMP FEP NUMBER: 2.2.07.11.01
FEP NAME: Auto-catalytic drainage of locally saturated flow thru condensation cap

ORIGINATOR FEP DESCRIPTION: Penetration of episodic flow down a fracture cools the surrounding rock below the vaporization temperature so that flow from the condensation cap can penetrate further, eventually reaching the waste and passing through the repository.

SECONDARY YMP FEP NUMBER: 2.2.07.11.02
FEP NAME: Resaturation, near-field rock

ORIGINATOR FEP DESCRIPTION: During the resaturation (and sealing) of the repository, flow directions are different and the hydraulic conductivity is different due to, for example, partially saturated fractures. Furthermore, (or especially) the groundwater chemistry is very different (oxidizing conditions exist).

SECONDARY YMP FEP NUMBER: 2.2.07.11.03
FEP NAME: Return of condensate to same panel

ORIGINATOR FEP DESCRIPTION: Condensate formed in the rock above the drift returns to the same panel through fractures (during the thermal period) or through the matrix (post-thermal).

SECONDARY YMP FEP NUMBER: 2.2.07.11.04
FEP NAME: Resaturation of dry-out zone is affected by vapor flow

ORIGINATOR FEP DESCRIPTION: The dry-out zone, the zone where the water content of the rock has been reduced by evaporation and 2-phase flow induced by repository heat, receives replacement water by transport of vapor from the water table and from surrounding country rock.

SECONDARY YMP FEP NUMBER: 2.2.07.11.05
FEP NAME: Resaturation of dry-out zone is effected by liquid under capillary forces

ORIGINATOR FEP DESCRIPTION: Liquid water returns by capillarity to the dryout zone (in the UZ) around the drifts as the rock cools below the vaporization temperature.

SECONDARY YMP FEP NUMBER: 2.2.07.11.06
FEP NAME: Unsaturated flow plume returns flow from the condensation cap

ORIGINATOR FEP DESCRIPTION: During the thermal period, a condensation zone - the condensation cap - forms above the drifts. When the rock has cooled the condensate returns to the rocks around the drifts and to the drifts as unsaturated flow, since the cap is heterogeneous, as an unsaturated flow plume.

PRIMARY YMP FEP NUMBER: 2.2.08.01.00
FEP NAME: Groundwater chemistry / composition in UZ and SZ

ORIGINATOR FEP DESCRIPTION: Identified as "groundwater chemistry" by originator. Refers to the groundwater chemistry in the geosphere (far-field rock) as well as changes in groundwater composition. The groundwater chemistry is dependent on the rock mineralogy through rock-water interactions and on other processes occurring in the groundwater, but also on interactions with other waters e.g. near-field waters, surface waters and saline waters. (SKI)

YMP PRIMARY FEP DESCRIPTION: Chemistry and and other characteristics of groundwater in the saturated and unsaturated zones may affect groundwater flow and radionuclide transport. Groundwater chemistry and other characteristics, including temperature, pH, Eh, ionic strength, and major ionic concentrations, may vary spatially throughout the system as a result of different rock mineralogy, and may also change through time, as a result of the evolution of the disposal system or from mixing with other waters.

SECONDARY YMP FEP NUMBER: 2.2.08.01.01
FEP NAME: Groundwater chemistry (in geosphere)

ORIGINATOR FEP DESCRIPTION: The groundwater chemistry is controlled by a range of factors, including the rock mineralogy, recharge conditions and residence time. ... For repository performance, the most important chemical parameters are the ionic strength, the pH and the Eh.

SECONDARY YMP FEP NUMBER: 2.2.08.01.02
FEP NAME: Deep saline water intrusion

ORIGINATOR FEP DESCRIPTION: Saline water is often present at repository depth and at larger depths. Changes in groundwater salinity will influence chemical equilibria, and salinity gradients may be of importance. etc.

SECONDARY YMP FEP NUMBER: 2.2.08.01.03
FEP NAME: Interface different waters (in geosphere)

ORIGINATOR FEP DESCRIPTION: Concerns the potential establishment of sharp interfaces between waters with different chemical composition, e.g. pH, salinity and redox conditions.

SECONDARY YMP FEP NUMBER: 2.2.08.01.04
FEP NAME: Water chemistry in near-field rock

ORIGINATOR FEP DESCRIPTION: Concerns the chemistry of the water in the rock surrounding the canister deposition holes and the tunnels in terms of the concentration of species which influence fracture properties and the speciation of radionuclides, as well as pH, redox and chemical gradients. etc.

SECONDARY YMP FEP NUMBER: 2.2.08.01.05
FEP NAME: Groundwater geochemistry (in geosphere)

ORIGINATOR FEP DESCRIPTION: The most important aspect of groundwater geochemistry in the region of the WIP in terms of chemical retardation and colloid stability is salinity.

SECONDARY YMP FEP NUMBER: 2.2.08.01.06
FEP NAME: Saline intrusion (in geosphere)

ORIGINATOR FEP DESCRIPTION: Natural changes in the groundwater chemistry of the Culebra and other units that resulted from saline intrusion could potentially affect chemical retardation and the stability of colloids. etc.

SECONDARY YMP FEP NUMBER: 2.2.08.01.07
FEP NAME: Freshwater intrusion (in geosphere)

ORIGINATOR FEP DESCRIPTION: Natural changes in the groundwater chemistry of the Culebra and other units that resulted from freshwater intrusion could potentially affect chemical retardation and the stability of colloids. etc.

SECONDARY YMP FEP NUMBER: 2.2.08.01.08
FEP NAME: Changes in groundwater Eh

ORIGINATOR FEP DESCRIPTION: Natural changes in the groundwater chemistry of the Culebra and other units could potentially affect chemical retardation and the stability of colloids. Changes in groundwater Eh could also affect the migration of radionuclides. etc.

SECONDARY YMP FEP NUMBER: 2.2.08.01.09
FEP NAME: Changes in groundwater pH

ORIGINATOR FEP DESCRIPTION: Natural changes in the groundwater chemistry of the Culebra and other units could potentially affect chemical retardation and the stability of colloids. Changes in groundwater pH could also affect the migration of radionuclides. etc.

SECONDARY YMP FEP NUMBER: 2.2.08.01.10
FEP NAME: Oxidizing conditions

ORIGINATOR FEP DESCRIPTION: This is evidently a special case of redox conditions in general. It might be limited in space and time (e.g. when considering redox fronts), or it might apply to all of the migration path through the geosphere.

SECONDARY YMP FEP NUMBER: 2.2.08.01.11
FEP NAME: Groundwater composition

ORIGINATOR FEP DESCRIPTION: Groundwater compositions, including changes due to activities such as construction of dams and pollution, could affect groundwater flow regimes; complexing agents could affect transport and dissolution of minerals and contaminants.

SECONDARY YMP FEP NUMBER: 2.2.08.01.12
FEP NAME: pH-deviations

ORIGINATOR FEP DESCRIPTION: It is perfectly clear that the pH value might vary considerably due to "natural" reasons within a repository and the geosphere. In Swedish bedrock the outer limits of this variation is set by the buffering action of minerals and dissolved carbonates, e.g. about pH 6.5-10.5. etc.

SECONDARY YMP FEP NUMBER: 2.2.08.01.13
FEP NAME: Change of groundwater chemistry in nearby rock

ORIGINATOR FEP DESCRIPTION: The presence of construction, backfill and other man-made materials will cause changes of the geochemistry in the near-field. Another source of such changes is the formation of radiolysis products. etc.

SECONDARY YMP FEP NUMBER: 2.2.08.01.14
FEP NAME: Saline (or fresh) groundwater intrusion

ORIGINATOR FEP DESCRIPTION: Saline water is often present at repository depths. Change in groundwater salinity will influence chemical equilibria, and salinity gradients might be of importance for groundwater flow.

SECONDARY YMP FEP NUMBER: 2.2.08.01.15
FEP NAME: Saline or freshwater intrusion

ORIGINATOR FEP DESCRIPTION: None.

SECONDARY YMP FEP NUMBER: 2.2.08.01.16
FEP NAME: Effects at saline-freshwater interface

ORIGINATOR FEP DESCRIPTION: None.

SECONDARY YMP FEP NUMBER: 2.2.08.01.17
FEP NAME: Chemical gradientsrface

ORIGINATOR FEP DESCRIPTION: None.

SECONDARY YMP FEP NUMBER: 2.2.08.01.18
FEP NAME: Non-radioactive solute plume in geosphere

ORIGINATOR FEP DESCRIPTION: None.

SECONDARY YMP FEP NUMBER: 2.2.08.01.19
FEP NAME: Groundwater chemistry (in geosphere)

ORIGINATOR FEP DESCRIPTION: The groundwater chemistry is controlled by a range of factors, including the rock mineralogy, recharge conditions and residence time. ... The groundwater chemistry of the LPD is assumed to be unperturbed by the presence of the repository. etc.

SECONDARY YMP FEP NUMBER: 2.2.08.01.20
FEP NAME: Intrusion of saline groundwater

ORIGINATOR FEP DESCRIPTION: Saline waters are found in the sedimentary units overlying the crystalline basement, in the Permo-Carboniferous Trough and, at a small number of sampling points, in the crystalline basement itself. etc.

SECONDARY YMP FEP NUMBER: 2.2.08.01.21
FEP NAME: Groundwater conditions

ORIGINATOR FEP DESCRIPTION: None.

SECONDARY YMP FEP NUMBER: 2.2.08.01.22
FEP NAME: Mineralogy (host rock)

ORIGINATOR FEP DESCRIPTION: The mineralogy of the LPD is heterogeneous. The average mineralogy of the water-conducting features differs from that of the undisturbed rock. etc.

SECONDARY YMP FEP NUMBER: 2.2.08.01.23
FEP NAME: Mineralogy (host rock)

ORIGINATOR FEP DESCRIPTION: The mineralogy of the Major Water-Conducting Faults is heterogeneous. The average mineralogy of the water-conducting features differs from that of the surrounding rock.

PRIMARY YMP FEP NUMBER: 2.2.08.02.00
FEP NAME: Radionuclide transport occurs in a carrier plume in geosphere

ORIGINATOR FEP DESCRIPTION: Identified as "Solute transport occurs in a carrier plume" by originator. Radionuclides are dissolved into the carrier plume (see 2.1.09k, 2.1.11h).

YMP PRIMARY FEP DESCRIPTION: Radionuclide transport occurs in a carrier plume in the geosphere. Transport may be as dissolved or colloidal species, and transport may occur in both the unsaturated and saturated zone. See also FEPs 2.1.09.01.00 (carrier plume forms in waste and EBS), 2.2.08.01.00 (groundwater chemistry / composition) and 2.2.08.03.00 (geochemical interactions).

SECONDARY YMP FEP NUMBER: 2.2.08.02.01
FEP NAME: Locally-saturated carrier plume forms (in geosphere)

ORIGINATOR FEP DESCRIPTION: When the flow system reestablishes itself through the repository, it is likely to do so before contaminants are mobile. This reestablished flow system, which can be a locally saturated system (fracture flow) carries the signature of the repository (pH, temperature, dissolved constituents, etc.) is termed the carrier plume.

SECONDARY YMP FEP NUMBER: 2.2.08.02.02
FEP NAME: Unsaturated carrier plume forms (in geosphere)

ORIGINATOR FEP DESCRIPTION: When the flow system reestablishes itself through the repository, it is likely to do so before contaminants are mobile. This reestablished flow system, which can be a UZ flow system, carries the signature of the repository (pH, temperature, dissolved constituents, etc.) is termed the carrier plume.

SECONDARY YMP FEP NUMBER: 2.2.08.02.03
FEP NAME: Precipitation/dissolution (release/migration factors)

ORIGINATOR FEP DESCRIPTION: Refers to the precipitation and dissolution of elements previously released from the fuel. This may occur as a consequence of changes in water chemistry. etc.

PRIMARY YMP FEP NUMBER: 2.2.08.03.00
FEP NAME: Geochemical interactions in geosphere (dissolution, precipitation, weathering) and effects on radionuclide transport

ORIGINATOR FEP DESCRIPTION: **Geochemical interactions may lead to dissolution and precipitation of minerals along the groundwater flow path, affecting groundwater flow, rock properties and sorption on contaminants.**

YMP PRIMARY FEP DESCRIPTION: Geochemical interactions may lead to dissolution and precipitation of minerals along the groundwater flow path, affecting groundwater flow, rock properties and sorption on contaminants. These interactions may result from the evolution of disposal system or from external processes such as weathering. Effects on hydrologic flow properties of the rock, radionuclide solubilities, sorption processes, and colloidal transport are relevant. Kinetics of chemical reactions should be considered in the context of the time-scale of concern. See also FEP 2.2.08.01.00 for a discussion of groundwater chemistry and composition, FEP 2.2.08.07.00 for a discussion of solubility limits in the geosphere, FEP 2.2.08.09.00 for a discussion of sorption in the geosphere, and FEPs 2.2.08.10.00 and 2.2.08.10.01 for a discussion of colloidal transport .

SECONDARY YMP FEP NUMBER: 2.2.08.03.01
FEP NAME: Far-field transport: Changes in groundwater chemistry and flow direction

ORIGINATOR FEP DESCRIPTION: It is inevitable that over the lifetime of the repository the groundwater chemistry and flow direction will change, e.g. due to changing recharge during glacial conditions. These changes may alter the sorption and desorption processes that occur on solid surfaces and may increase or decrease the sorptive capacity of the far-field rocks.

SECONDARY YMP FEP NUMBER: *2.2.08.03.02*
FEP NAME: *Effects of dissolution (in geosphere)*

ORIGINATOR FEP DESCRIPTION: Natural changes in the groundwater chemistry of the Culebra and other units could potentially affect chemical retardation and the stability of colloids. The magnitude of any natural temporal variation due to the effects of dissolution on groundwater chemistry is likely to be no greater than the present spatial variation. etc.

SECONDARY YMP FEP NUMBER: *2.2.08.03.03*
FEP NAME: *Rock property changes (in geosphere)*

ORIGINATOR FEP DESCRIPTION: Changes in the porosity and permeability properties of the rock due to processes may alter the groundwater flow-field and, thus, radionuclide transport in the far-field. ... The only rock property changes that are important to consider in the far-field are increases and decreases in permeability and a number of processes mat occur that affect these properties of the rock mass.

SECONDARY YMP FEP NUMBER: *2.2.08.03.04*
FEP NAME: *Hydraulic properties-evolution*

ORIGINATOR FEP DESCRIPTION: The precipitation and dissolution of material could affect the groundwater flow regime by plugging or opening pores and fractures. This process could be enhanced by differential solubilities in a thermal gradient. etc.

SECONDARY YMP FEP NUMBER: *2.2.08.03.05*
FEP NAME: *Dissolution of fracture fillings/precipitations (in geosphere)*

ORIGINATOR FEP DESCRIPTION: Fracture fillings are dissolved by groundwater for whatever unspecified reasons (e.g. temperature change).

SECONDARY YMP FEP NUMBER: *2.2.08.03.06*
FEP NAME: *Weathering of flow paths (in geosphere)*

ORIGINATOR FEP DESCRIPTION: Ongoing chemical reactions between groundwater and rock and fracture minerals lead to more or less continuous changes of the solid phases along the flow paths from a repository. Thus, not only weathering of rock minerals take place, but also healing of existing and newly formed fractures. etc.

SECONDARY YMP FEP NUMBER: *2.2.08.03.07*
FEP NAME: *Fracture mineralization and weathering (in geosphere)*

ORIGINATOR FEP DESCRIPTION: None.

SECONDARY YMP FEP NUMBER: *2.2.08.03.08*
FEP NAME: *Alteration/weathering of flow paths*

ORIGINATOR FEP DESCRIPTION: Ongoing chemical reactions between groundwater and rock- and fracture minerals lead to more or less continuous changes of the solid phases along the flow paths from a repository. Thus, not only weathering of rock minerals takes place, but also healing of existing and newly formed fractures.

SECONDARY YMP FEP NUMBER: *2.2.08.03.09*
FEP NAME: *Precipitation and dissolution (release/migration factors)*

ORIGINATOR FEP DESCRIPTION: Contaminants, primary minerals and rock alteration products could be subjected to precipitation and dissolution at different points along their flow paths, due to changes in temperature (thermal gradients), groundwater chemistry, flow rates and mineralogy or the presence of microbes.

SECONDARY YMP FEP NUMBER: 2.2.08.03.10
FEP NAME: Chemical precipitation (release/migration factors)

ORIGINATOR FEP DESCRIPTION: An important determinant in the transfer of contaminants in the environment is mobility. Highly mobile contaminants tend to reach humans and other organisms, and increase radiation exposure. Chemical precipitation in surface water, wetlands and soils tends to reduce mobility and thereby doses.

SECONDARY YMP FEP NUMBER: 2.2.08.03.11
FEP NAME: Dissolution, precipitation and crystallization (release/migration factors)

ORIGINATOR FEP DESCRIPTION: None.

SECONDARY YMP FEP NUMBER: 2.2.08.03.12
FEP NAME: Kinetics of precipitation and dissolution (release/migration factors)

ORIGINATOR FEP DESCRIPTION: At low temperatures, precipitation and dissolution reactions are caused by changes in fluid chemistry that result in chemical undersaturation or oversaturation (Bruno and Sandino 1987).

SECONDARY YMP FEP NUMBER: 2.2.08.03.13
FEP NAME: Speciation (contaminant speciation and solubility)

ORIGINATOR FEP DESCRIPTION: Chemical speciation will affect dissolution and precipitation, and change with time following the thermal pulse.

SECONDARY YMP FEP NUMBER: 2.2.08.03.14
FEP NAME: Speciation (geosphere) (contaminant speciation and solubility)

ORIGINATOR FEP DESCRIPTION: Speciation of contaminants in waters containing different inorganic and organic components will affect mobility and sorption.

SECONDARY YMP FEP NUMBER: 2.2.08.03.15
FEP NAME: Recrystallization (contaminant speciation and solubility)

ORIGINATOR FEP DESCRIPTION: Recrystallization is linked to solubility phenomena and changes to water chemistry, in turn coupled to radiolysis. Recrystallization may also refer to the long-term alteration of a cement matrix, i.e. crystallization of calcium silicate hydrates.

SECONDARY YMP FEP NUMBER: 2.2.08.03.16
FEP NAME: Speciation (contaminant speciation and solubility)

ORIGINATOR FEP DESCRIPTION: Radionuclide behavior will be determined by the physio-chemical matrix or form in which the radionuclide is incorporated, or speciation if in aqueous solution.

SECONDARY YMP FEP NUMBER: 2.2.08.03.17
FEP NAME: Kinetics of speciation (contaminant speciation and solubility)

ORIGINATOR FEP DESCRIPTION: The effects of reaction kinetics in aqueous systems are discussed by Lasaga et al (1994) who suggest that in contrast to many heterogeneous reactions, homogeneous aqueous geochemical speciation reactions involving relatively small inorganic species occur rapidly and are accurately described by thermodynamic equilibrium models that neglect explicit consideration of reaction kinetics.

SECONDARY YMP FEP NUMBER: 2.2.08.03.18
FEP NAME: Groundwater chemistry (sorption/desorption processes)

ORIGINATOR FEP DESCRIPTION: The groundwater chemistry is controlled by a range of factors, including the rock mineralogy, recharge conditions and residence time. For repository performance, the most important chemical parameters are the ionic strength, the pH and the Eh. etc.

PRIMARY YMP FEP NUMBER: 2.2.08.05.00
FEP NAME: Osmotic processes

ORIGINATOR FEP DESCRIPTION: Under appropriate circumstances, osmotic processes may occur at interfaces between waters of different salinities. Osmosis is the process by which water (or any solvent) diffuses through a semi-permeable (or differentially permeable) membrane in response to a concentration gradient. At WIPP, clay layers may act as semi-permeable membranes across which osmotic processes may occur.

YMP PRIMARY FEP DESCRIPTION: Osmotic processes in response to chemical gradients could affect radionuclide transport in the geosphere. See also FEP 2.2.08.08.00, matrix diffusion.

SECONDARY YMP FEP NUMBER: None
FEP NAME: None

ORIGINATOR FEP DESCRIPTION: None.

PRIMARY YMP FEP NUMBER: 2.2.08.06.00
FEP NAME: Complexation in geosphere

ORIGINATOR FEP DESCRIPTION: **(Identified as "Complexing agents" by originator)**
The presence of naturally occurring complexing agents is well established even for deep groundwaters, e.g. those deriving from humic and fulvic acids. Thus, their effect on barrier performance should be included in the process system. etc.

YMP PRIMARY FEP DESCRIPTION: Complexing agents such as humic and fulvic acids present in natural groundwaters could affect radionuclide transport. See also FEP 2.1.09.13.00 for a discussion of complexing agents in the waste and EBS.

SECONDARY YMP FEP NUMBER: None
FEP NAME: None

ORIGINATOR FEP DESCRIPTION: None.

PRIMARY YMP FEP NUMBER: 2.2.08.07.00
FEP NAME: Radionuclide solubility limits in the geosphere

ORIGINATOR FEP DESCRIPTION: **Identified as "Far-field transport: Solubility constraints" by originator. The solubility of radionuclides is controlled by a number of factors, notably pH and Eh. The far-field chemistry is less perturbed by the presence of the repository than the near-field chemistry and, consequently, solubility constraints in the far-field can be less significant. However, the alkaline plume migrating from the near-field may cause significant perturbation in far-field chemistry and control radionuclide solubilities there.**

YMP PRIMARY FEP DESCRIPTION: Solubility limits for radionuclides may different in geosphere groundwater than in the water in the waste and EBS. See also FEP 2.2.08.01.00 for a discussion of groundwater chemistry and FEP 2.1.09.04.00 for a discussion of solubility limits in the waste and EBS.

SECONDARY YMP FEP NUMBER: 2.2.08.07.01
FEP NAME: Radionuclide transport through LPD (water transport)

ORIGINATOR FEP DESCRIPTION: Solubility limits appropriate to the groundwater chemistry are not expected to be exceeded and so radionuclides in the LPD would exist either in solution in pores within the rock or sorbed onto solid surfaces.

SECONDARY YMP FEP NUMBER: 2.2.08.07.02
FEP NAME: Radionuclide transport through MWCF (water transport)

ORIGINATOR FEP DESCRIPTION: Solubility limits appropriate to the groundwater chemistry are not expected to be exceeded and so radionuclides in the Major Water-Conducting Faults would exist either in solution in pores within the rock or sorbed onto solid surfaces. In pores through which groundwater flow occurs, predominantly the open channels of the small-scale water-conducting features, radionuclides in solution would be transported by advection. etc.

SECONDARY YMP FEP NUMBER: 2.2.08.07.03
FEP NAME: Solubility limits/colloid formation

ORIGINATOR FEP DESCRIPTION: Solubility limits are unlikely to be reached in the far field except for naturally occurring nuclides, e.g. uranium isotopes.

SECONDARY YMP FEP NUMBER: 2.2.08.07.04
FEP NAME: Solubility limits/colloid formation

ORIGINATOR FEP DESCRIPTION: Solubility limits are unlikely to be reached in the far field except for naturally occurring nuclides, e.g. uranium isotopes.

PRIMARY YMP FEP NUMBER: 2.2.09.01.00
FEP NAME: Microbial activity in geosphere

ORIGINATOR FEP DESCRIPTION: **Identified as "Microbial activity" by originator.**
Microbes will be naturally present in the system, but in low numbers due to low nutrient and energy availability. They may have a minor effect on radionuclide mobility that is small within the uncertainties in physical/chemical transport processes.

YMP PRIMARY FEP DESCRIPTION: Microbial activity in the geosphere may affect radionuclide mobility in rock and soil through colloidal processes, by influencing the availability of complexing agents, or by influencing groundwater chemistry. See also FEP 2.2.08.10.00 for a discussion of colloidal transport and 2.2.08.06.00 for a discussion of complexing agents.

SECONDARY YMP FEP NUMBER: 2.2.09.01.01
FEP NAME: Microbes (in geosphere)

ORIGINATOR FEP DESCRIPTION: Incorporation of contaminants into or onto microbes or bacteria could affect the rate of transport of contaminants. The activity of microorganisms could affect the mobility of contaminants by methylating heavy metals, releasing organic ligands with a high complexing capacity, affecting the groundwater pH and redox, and reducing permeability in fractures.

SECONDARY YMP FEP NUMBER: 2.2.09.01.02
FEP NAME: Microbes (in geosphere)

ORIGINATOR FEP DESCRIPTION: Microorganisms exist in geologic environments. ... Possible adverse consequences of microbial activities are production of corrosive agents and gases. Either the microbes themselves or substances produced by the microbes can be imagined to take up radionuclides by sorption or complex formation.

SECONDARY YMP FEP NUMBER: 2.2.09.01.03
FEP NAME: Microbial activity (in geosphere)

ORIGINATOR FEP DESCRIPTION: Microbes will be naturally present in the system, but in low numbers due to low nutrient and energy availability. They may have a minor effect on radionuclide mobility that is small within the uncertainties in physical/chemical transport processes.

SECONDARY YMP FEP NUMBER: 2.2.09.01.04
FEP NAME: Far-field transport: Biogeochemical changes

ORIGINATOR FEP DESCRIPTION: The surface environment will change over the lifetime of the repository due to changes in climate. The biological (microbial) load of recharge water may also change and this could affect the transport of radionuclides in the field.

SECONDARY YMP FEP NUMBER: 2.2.09.01.05
FEP NAME: Bacteria and microbes in soil

ORIGINATOR FEP DESCRIPTION: These organisms help to decompose organic matter in the soil and liberate contaminants, which may then be leached or recycled. Bacteria and microbes may also chemically transform contaminants and thereby change their mobility in the environment.

SECONDARY YMP FEP NUMBER: 2.2.09.01.06
FEP NAME: Chemical transformations (biological processes)

ORIGINATOR FEP DESCRIPTION: None.

PRIMARY YMP FEP NUMBER: 2.2.10.01.00
FEP NAME: Repository-induced thermal effects in geosphere

ORIGINATOR FEP DESCRIPTION: **None.**

YMP PRIMARY FEP DESCRIPTION: Thermal effects in the geosphere could affect the long-term performance of the disposal system. Thermal effects are most important in waste, engineered barrier system, and the disturbed zone surrounding the excavation. See FEPs 2.1.11.00.00 and 2.2.01.00.00 for discussions of this region. See other FEPs in this section for specific discussions of thermal effects in geosphere, including effects on saturated and unsaturated groundwater flow, mechanical properties, and chemical effects.

SECONDARY YMP FEP NUMBER: 2.2.10.01.01
FEP NAME: Temperature, far-field

ORIGINATOR FEP DESCRIPTION: The temperature in the far-field rock depends on the location and depth of the repository and on the thermal properties of the rock and the groundwater. [The point of the FEP is that far-field temperature affects stress, groundwater flow, water chemistry, weathering of rocks, diffusion, thermal properties, etc.

SECONDARY YMP FEP NUMBER: 2.2.10.01.02
FEP NAME: Temperature, near-field rock

ORIGINATOR FEP DESCRIPTION: The location and depth of the repository will affect the temperature in the surrounding rock, but the temperature in the nearby rock will also be affected by the ventilation of the repository during construction and operation.

SECONDARY YMP FEP NUMBER: 2.2.10.01.03
FEP NAME: Thermal effects on groundwater flow

ORIGINATOR FEP DESCRIPTION: The geothermal gradient in the region of the WIPP has been measured at about 50 C per mile (30 C per km). Given the low permeability in the region, and the limited thickness of units in which groundwater flow occurs (for example the Culebra), natural convection will be too weak to have a significant effect on groundwater flow. etc.

SECONDARY YMP FEP NUMBER: 2.2.10.01.04
FEP NAME: Groundwater - evolution

ORIGINATOR FEP DESCRIPTION: Groundwater compositions will evolve, due to the presence of the vault as a heat source.

SECONDARY YMP FEP NUMBER: 2.2.10.01.05
FEP NAME: Thermal effects on material properties (in waste and EBS)

ORIGINATOR FEP DESCRIPTION: Potentially, thermal effects on material properties (such as permeability and porosity) could affect the behavior of the repository.

SECONDARY YMP FEP NUMBER: 2.2.10.01.06
FEP NAME: Thermal effects: Rock-mass changes

ORIGINATOR FEP DESCRIPTION: The thermal pulse generated in the intermediate-level waste will cause the near-field rock to heat up possibly changing its physical properties, which in turn could affect radionuclide transport in the far-field.

SECONDARY YMP FEP NUMBER: 2.2.10.01.07
FEP NAME: Thermal effects: Hydrogeological changes

ORIGINATOR FEP DESCRIPTION: The thermal pulse generated in the intermediate-level waste may cause the groundwater flow paths to change direction due to the existence of buoyancy forces. The thermal pulse is believed to be sufficient to perturb the groundwater flow paths in the far-field. etc.

PRIMARY YMP FEP NUMBER: 2.2.10.04.00
FEP NAME: Thermo-mechanical alteration of fractures near repository

ORIGINATOR FEP DESCRIPTION: Identified as "Thermo-mechanical alteration of stress-state in rock surrounding drifts" by originator. Heat from the waste causes thermal expansion of the surrounding rock, generating compressive stresses near the drifts and extensional stresses away from them. The zone of compression migrates with time.

YMP PRIMARY FEP DESCRIPTION: Heat from the waste causes thermal expansion of the surrounding rock, generating changes in the stress field that may change the material properties (both hydrologic and mechanical) of fractures in the rock. Cooling following the peak thermal period will also change the stress field, further affecting rock properties near the repository.

SECONDARY YMP FEP NUMBER: 2.2.10.04.01
FEP NAME: Thermal expansion closes most fractures close to repository

ORIGINATOR FEP DESCRIPTION: Thermal expansion closes most fractures near the repository. Preexisting fracture percolation is diverted into fractures of larger aperture.

SECONDARY YMP FEP NUMBER: 2.2.10.04.02
FEP NAME: Thermally-induced fracturing around containers creates a capillary barrier

ORIGINATOR FEP DESCRIPTION: Thermally induced fracturing of rocks immediately surrounding waste canisters creates capillary barriers to movement of moisture between blocks of rock matrix. The matrix is locally saturated, forcing flow out into the fractures and resulting in film flow or droplet impact on waste packages. The result is accelerated localized corrosion and waste dissolution.

SECONDARY YMP FEP NUMBER: 2.2.10.04.03
FEP NAME: Host rock fracture aperture changes

ORIGINATOR FEP DESCRIPTION: None.

PRIMARY YMP FEP NUMBER: 2.2.10.05.00
FEP NAME: Thermo-mechanical alteration of rocks above and below the repository

ORIGINATOR FEP DESCRIPTION: **Identified as "Alteration of the PTn unit by thermo-mechanical stress" by originator. Thermo-mechanical compression at the repository produces tension-fracturing in the PTn above the repository. (YMP).**

YMP PRIMARY FEP DESCRIPTION: **Thermo-mechanical compression at the repository produces tension-fracturing in the PTn and other units above the repository. These fractures alter unsaturated zone flow between the surface and the repository. Extreme fracturing may propagate to the surface, affecting infiltration. Thermal fracturing in rocks below the repository affects flow and radionuclide transport to the saturated zone.**

SECONDARY YMP FEP NUMBER: 2.2.10.05.01
FEP NAME: Thermal expansion of rocks below repository opens fractures in Paint Brush unwelded

ORIGINATOR FEP DESCRIPTION: Rock movements driven by thermal expansion of underlying units open fractures through the Paintbrush nonwelded unit. This creates local zones of increased flux through the unsaturated units below.

SECONDARY YMP FEP NUMBER: 2.2.10.05.02
FEP NAME: Thermo-mechanical alteration of surface infiltration

ORIGINATOR FEP DESCRIPTION: Thermal expansion of rocks adjacent to the repository produces tension fractures which reach the surface and affect location and amount of infiltration.

PRIMARY YMP FEP NUMBER: 2.2.10.06.00
FEP NAME: Thermo-chemical alteration (solubility, speciation, phase changes, precipitation/dissolution)

ORIGINATOR FEP DESCRIPTION: **Identified as "Far-field transport: Thermal effects on hydrochemistry" by originator.**

Changes in the groundwater temperature in the far-field, if significant, may change the solubility and speciation of certain radionuclides. This would have the effect of altering radionuclide transport processes operating in the far-field.

YMP PRIMARY FEP DESCRIPTION: **Thermal effects may affect radionuclide transport directly by causing changes radionuclide speciation and solubility in the UZ and SZ, or indirectly, by causing changes in host rock mineralogy that affect the flow path. Relevant processes include volume effects associated with silica phase changes, precipitation and dissolution of fracture-filling minerals (including silica and calcite), and alteration of zeolites and other minerals to clays.**

SECONDARY YMP FEP NUMBER: 2.2.10.06.01
FEP NAME: Silica phase changes (accompanied by volume change) occur due to elevated temperature

ORIGINATOR FEP DESCRIPTION: Certain minerals associated with the tuffs are found to undergo phase changes and dewater at relatively low temperature <150 C. The associated volume changes are large and for substantial concentrations of these minerals significant.

SECONDARY YMP FEP NUMBER: 2.2.10.06.02
FEP NAME: Thermochemical change

ORIGINATOR FEP DESCRIPTION: This FEP should be interpreted as the influence on all chemical equilibria (and reaction kinetics, for that matter) of changes in temperature.

SECONDARY YMP FEP NUMBER: 2.2.10.06.03
FEP NAME: Alteration of rock properties because of 2-phase flow

ORIGINATOR FEP DESCRIPTION: Thermally-driven 2-phase flow of water will put hot water or water vapor in contact with rock, producing altered phases(e.g. vitric units converted to clays and zeolites with volume changes) which will alter permeabilities.

SECONDARY YMP FEP NUMBER: 2.2.10.06.04
FEP NAME: Heat-induced chemical reactions plug small fractures; flow is preferentially redirected to large fractures

ORIGINATOR FEP DESCRIPTION: Chemical reactions induced by repository heat plug smaller-aperture fractures. After the thermal pulse ends, percolation is diverted into larger fractures.

SECONDARY YMP FEP NUMBER: 2.2.10.06.05
FEP NAME: Alteration of minerals to clays (in geosphere)

ORIGINATOR FEP DESCRIPTION: Minerals adjacent to the residual water-bearing pores are thermally altered to clays.

SECONDARY YMP FEP NUMBER: 2.2.10.06.06
FEP NAME: Calcite precipitation in hot region produces fluids depleted in calcite which dissolve calcite below the repository

ORIGINATOR FEP DESCRIPTION: Water passing through the warm region around the repository is depleted of calcite by temperature-induced precipitation. Below the repository, the calcite-poor water dissolves out calcite veins in the Calico Hills nonwelded unit.

SECONDARY YMP FEP NUMBER: 2.2.10.06.07
FEP NAME: Precipitates from dissolved constituents of tuff and repository materials form by evaporation during thermal period

ORIGINATOR FEP DESCRIPTION: Waters moving away from the hot region around the repository precipitate minerals derived from dissolved constituents of tuff and cements used in repository construction. These minerals clog pores and divert subsequent flow into fractures.

PRIMARY YMP FEP NUMBER: 2.2.10.07.00
FEP NAME: Thermo-chemical alteration of the Calico Hills unit

ORIGINATOR FEP DESCRIPTION: **Identified as "Alteration of the Calico Hills fractures" by originator. Fracture pathways in the Calico Hills are altered by the high pH fluids forming the carrier plume.**

YMP PRIMARY FEP DESCRIPTION: **Fracture pathways in the Calico Hills are altered by the thermal and chemical properties of the water flowing out of the repository.**

SECONDARY YMP FEP NUMBER: None
FEP NAME: None

ORIGINATOR FEP DESCRIPTION: None.

PRIMARY YMP FEP NUMBER: 2.2.10.09.00
FEP NAME: Thermo-chemical alteration of the Topopah Spring basal vitrophyre

ORIGINATOR FEP DESCRIPTION: **Identified as "Alteration of the Topopah Spring basal vitrophyre" by originator. Heating the Topopah Spring basal vitrophyre with water available causes alteration of the glasses to clays and zeolites, with a volume increase.**

YMP PRIMARY FEP DESCRIPTION: **Heating the Topopah Spring basal vitrophyre with water available causes alteration of the glasses to clays and zeolites. Possible effects include volume increases that plug fractures, changes in flow paths, creation of perched water zones, and an increase in the sorptive properties of the unit.**

SECONDARY YMP FEP NUMBER: 2.2.10.09.01
FEP NAME: Formation of perched water on the altered Topopah Spring basal vitrophyre

ORIGINATOR FEP DESCRIPTION: The topography of the altered TPS basal vitrophyre allows local low areas to form, in which drainage can accumulate as perched water (possibly contaminated).

SECONDARY YMP FEP NUMBER: 2.2.10.09.02
FEP NAME: Sorption of contaminants by the altered Topopah Spring basal vitrophyre

ORIGINATOR FEP DESCRIPTION: Heating the Topopah Spring basal vitrophyre with water available causes alteration of the glasses to clays and zeolites. Such alterations affect and probably enhance the sorption properties of this unit.

SECONDARY YMP FEP NUMBER: 2.2.10.09.03
FEP NAME: Redirection of transport paths by the altered Topopah Spring basal vitrophyre

ORIGINATOR FEP DESCRIPTION: Heating the Topopah Spring basal vitrophyre with water available causes alteration of the glasses to clays and zeolites. Such alterations probably alter the direction of flow, plugging some fracture pathways, causing accumulation of perched water and then redirecting the flow.

SECONDARY YMP FEP NUMBER: 2.2.10.09.04
FEP NAME: Sorption of actinides on altered Topopah Spring basal vitrophyre

ORIGINATOR FEP DESCRIPTION: Actinides are sorbed on the clays and zeolites which are the alteration products of the vitric components of the Topopah Spring basal vitrophyre.

SECONDARY YMP FEP NUMBER: 2.2.10.09.05
FEP NAME: Alteration of the Topopah Spring basal vitrophyre

ORIGINATOR FEP DESCRIPTION: Alteration of the Topopah Spring basal vitrophyre causes a volumetric expansion.

ATTACHMENT IX

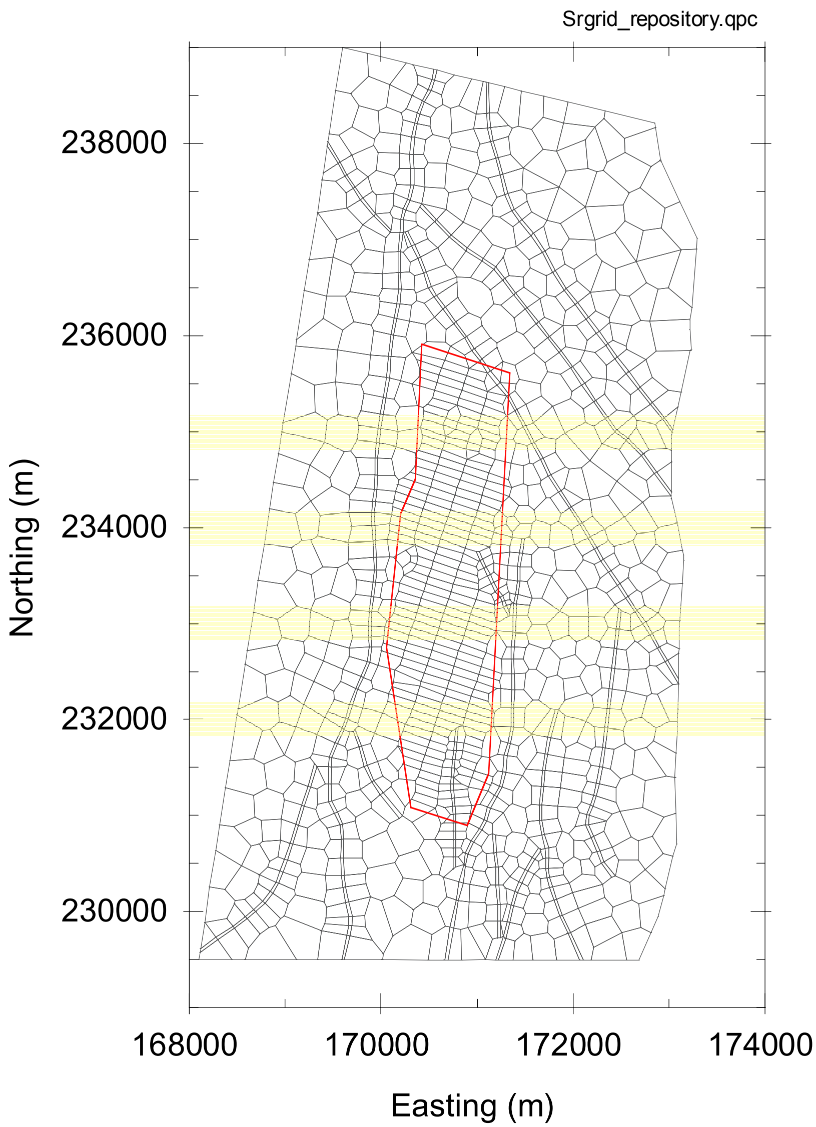
LOCATION OF PTN ELEMENTS ALONG FOUR TRANSECTS

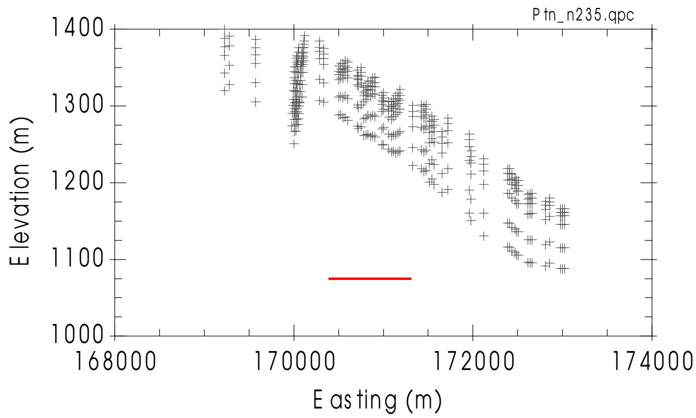
To address the issue of episodic transient percolation, the location of the PTn elements are plotted along four east-west transects (N232,000, N233,000, N234,000, and N235,000), which are shown in the plot to the right. Each transect has a tolerance of ± 200 m in the northing direction.

Each transect plot on the following page shows the location of the PTn element (symbols) along with the approximate location of the repository shown in red (outline obtained from DTN: SN9907T0872799.001). The coordinates of the elements originate from the LBNL mesh file (mpa_pch1.v1) that was transmitted with an Input Transmittal (ITN: SNL-LBL-99249.Tb; DTN: LB990701233129.001).

Note that although the PTn thins to the south, PTn material still exists everywhere above the repository. The existence of the PTn above the repository elements should dampen the effects of episodic transient percolation.

The souce code and output data from this calculation can be found the the Technical Data Management System under DTN: under DTN: MO9912 SPAPTN01.006.





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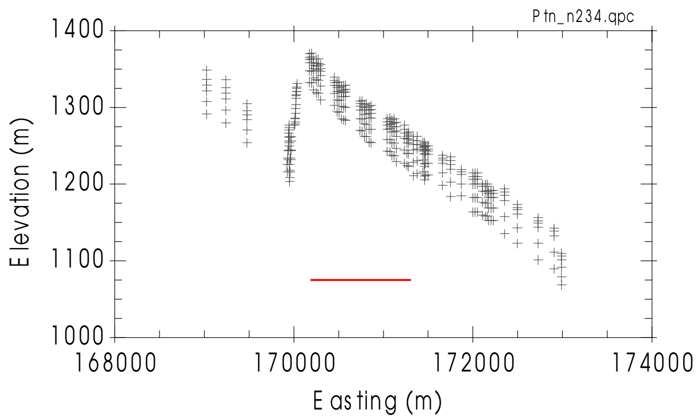
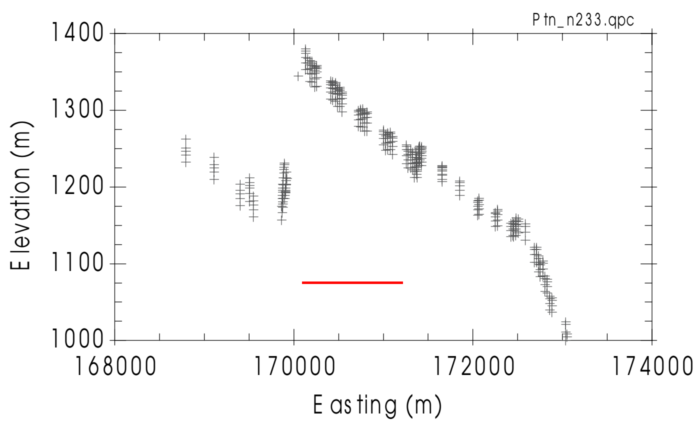
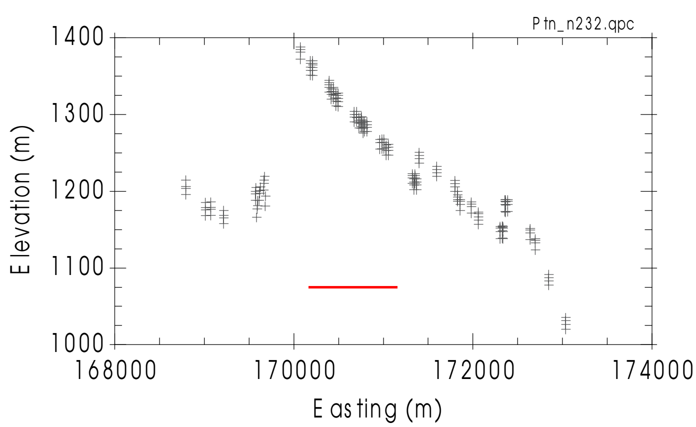


N234,000 m

East-west cross-sectional plots showing occurence of the PTn hydrogeologic unit



N233,000 m



N232,000 m

Source File: ptn_v1.f V1

```
c     program ptn_v1.f V1
c______________________________________________________________________
c
c  This program extracts four east-west transects from the LBNL site
c  model grid that contain PTn matrix elements that were grepped from
c  the original mesh file (grep 'ptnM' mpa_pch1.v1 > ptn_elem.dat).
c  The elements, materials, volumes, and coordinates are then printed
c  to four separate output files corresponding the each transect.
c
c    C.K.Ho
c    11/23/99
c______________________________________________________________________
c234567890123456789012345678901234567890123456789012345678901234567890123456789012

      character*5 elem, mat

      open(1,file='ptn_elem.dat',status='old')
      open(2,file='ptn_N232.dat',status='unknown')
      open(3,file='ptn_N233.dat',status='unknown')
      open(4,file='ptn_N234.dat',status='unknown')
      open(5,file='ptn_N235.dat',status='unknown')

c...Data
      ntol=200
      n232max=232000+ntol
      n232min=232000-ntol
      n233max=233000+ntol
      n233min=233000-ntol
      n234max=234000+ntol
      n234min=234000-ntol
      n235max=235000+ntol
      n235min=235000-ntol

c...Write headers to output files
      write(2,50)
50    format('***Output file from ptn_v1.f:  ptn_N232.dat***'/
     &  'PTn elements from mpa_pch1.v1 that fall within '
     &  'the band N232,000 m plus/minus 200 m'/
     &  'Element, material, volume(m^3), x(m), y(m), z(m)')
      write(3,60)
60    format('***Output file from ptn_v1.f:  ptn_N233.dat***'/
     &  'PTn elements from mpa_pch1.v1 that fall within '
     &  'the band N233,000 m plus/minus 200 m'/
     &  'Element, material, volume(m^3), x(m), y(m), z(m)')
      write(4,70)
70    format('***Output file from ptn_v1.f:  ptn_N234.dat***'/
     &  'PTn elements from mpa_pch1.v1 that fall within '
     &  'the band N234,000 m plus/minus 200 m'/
     &  'Element, material, volume(m^3), x(m), y(m), z(m)')
      write(5,80)
80    format('***Output file from ptn_v1.f:  ptn_N235.dat***'/
     &  'PTn elements from mpa_pch1.v1 that fall within '
     &  'the band N235,000 m plus/minus 200 m'/
     &  'Element, material, volume(m^3), x(m), y(m), z(m)')

c...Read information from ptn_elem.dat
7     read(1,10,end=99) elem,mat,vol,x,y,z
10    format(a5,10x,a5,e10.4,20x,3f10.4)

c...Check to see if element lies within one of the transects.
c...If so, print the information to the respective output file.
      if(y.lt.n232max.and.y.gt.n232min) then
        write(2,20) elem,mat,vol,x,y,z
20      format(2(a5,', '),e10.4,', ',2(f10.3,', '),f10.4)
      elseif(y.lt.n233max.and.y.gt.n233min) then
        write(3,20) elem,mat,vol,x,y,z
      elseif(y.lt.n234max.and.y.gt.n234min) then
        write(4,20) elem,mat,vol,x,y,z
```

```
      elseif(y.lt.n235max.and.y.gt.n235min) then
        write(5,20) elem,mat,vol,x,y,z
      end if

      go to 7

99    stop
      end
```

There are four output data files that present the coordinates of the PTn for a given east-west transect identified by northing coordinate. Each transect includes occurrences of the PTn " 200 meters from the given northing coordinate. The output is written in the following manner:

The four northing coordinates (in meters) used for the transects are:

232,000
233,000
234,000
235,000

Grid identifier, hydrogeologic unit identifier, grid volume (in m^3), and grid coordinates northing, easting, and elevation above sea level, respectively, all in meters. The output confirms that the nodes selected are from the PTn within the " 200m interval of the selected cross sections.

Sample output data from: Ptn_n232.dat

```
***Output file from ptn_v1.f:  ptn_N232.dat***
PTn elements from mpa_pch1.v1 that fall within the band N232,000 m plus/minus 200 m
Element, material, volume(m^3), x(m), y(m), z(m)
Mca47, ptnM1, 0.1259E+06, 172848.000, 232093.734,  1091.8849
Mda47, ptnM4, 0.4190E+06, 172848.000, 232093.734,  1087.6178
Mea47, ptnM5, 0.1143E+06, 172848.000, 232093.734,  1083.4457
Mfa47, ptnM6, 0.6340E+06, 172848.000, 232093.734,  1077.6309
Mca98, ptnM1, 0.1152E+06, 172634.969, 232149.438,  1151.3610
Mda98, ptnM3, 0.1107E+06, 172634.969, 232149.438,  1149.4645
Mea98, ptnM4, 0.3410E+06, 172634.969, 232149.438,  1145.6630
Mfa98, ptnM6, 0.6949E+06, 172634.969, 232149.438,  1136.9746
```

Sample output data from: Ptn_n233.dat

```
***Output file from ptn_v1.f:  ptn_N233.dat***
PTn elements from mpa_pch1.v1 that fall within the band N233,000 m plus/minus 200 m
Element, material, volume(m^3), x(m), y(m), z(m)
Mda27, ptnM1, 0.1541E+06, 173034.625, 233184.234,  1024.7982
Mea27, ptnM4, 0.3840E+06, 173034.625, 233184.234,  1020.7847
Mfa27, ptnM5, 0.9222E+06, 173034.625, 233184.234,  1011.0783
Mga27, ptnM6, 0.5782E+06, 173034.625, 233184.234,   999.9597
Mda43, ptnM1, 0.1543E+06, 172273.734, 233195.266,  1171.1655
Mea43, ptnM2, 0.1500E+06, 172273.734, 233195.266,  1168.7477
Mfa43, ptnM4, 0.4731E+06, 172273.734, 233195.266,  1163.7947
Mga43, ptnM5, 0.3265E+06, 172273.734, 233195.266,  1157.4543
```

Sample output data from: Ptn_n234.dat

```
***Output file from ptn_v1.f:  ptn_N234.dat***
PTn elements from mpa_pch1.v1 that fall within the band N234,000 m plus/minus 200 m
Element, material, volume(m^3), x(m), y(m), z(m)
Mca18, ptnM1, 0.3144E+06, 172726.297, 234098.813,  1156.3379
Mda18, ptnM2, 0.2252E+06, 172726.297, 234098.813,  1152.1523
Mea18, ptnM3, 0.1184E+06, 172726.297, 234098.813,  1149.4949
Mfa18, ptnM4, 0.5777E+06, 172726.297, 234098.813,  1144.1017
Mga18, ptnM5, 0.2157E+07, 172726.297, 234098.813,  1122.9805
Mha18, ptnM6, 0.6561E+06, 172726.297, 234098.813,  1101.2928
Mda61, ptnM1, 0.2564E+06, 172990.063, 233838.844,  1109.7997
Mea61, ptnM2, 0.1549E+06, 172990.063, 233838.844,  1106.5591
```

Sample output data from: Ptn_n235.dat

```
***Output file from ptn_v1.f:  ptn_N235.dat***
PTn elements from mpa_pch1.v1 that fall within the band N235,000 m plus/minus 200 m
Element, material, volume(m^3), x(m), y(m), z(m)
Mca 8, ptnM1, 0.2360E+06, 171957.781, 235171.875,  1263.6887
Mda 8, ptnM2, 0.7768E+06, 171957.781, 235171.875,  1256.6512
Mea 8, ptnM3, 0.5318E+06, 171957.781, 235171.875,  1247.5916
Mfa 8, ptnM4, 0.2115E+07, 171957.781, 235171.875,  1229.2262
Mga 8, ptnM5, 0.3462E+07, 171957.781, 235171.875,  1190.5944
Mha 8, ptnM6, 0.8896E+06, 171957.781, 235171.875,  1160.5358
Mca23, ptnM1, 0.1756E+06, 172807.984, 234967.563,  1176.2024
Mda23, ptnM2, 0.3997E+06, 172807.984, 234967.563,  1170.8516
```

ATTACHMENT X

FRACTURE WATER VOLUME IN THE PERCHED WATER ZONE; PERCOLATION FLUX AT THE REPOSITORY HORIZON

Software routine ‘perch_ele.f’V1

This routine is for identifying perched-water elements within and below the repository footprint and calculating the volume of water in these elements. Input and output files are explained in the comment section of the program. The code and its output files can be found in the technical database under the data tracking number ‘MO9912SPAPWI01.006’. The input files are in ‘LB990801233129.001’ through ‘LB990801233129.012’.

(1) Code Listing:

```
c
c     To identify elements in perched-water zones, then identify
c     those perched-water elements within and below
c     the repository area, and then calculate the volume of
c     water in these repository footprint perched-water elements.
c
c     input files:
c        --- INCON or SAVE file.
c        --- MESH or its ELEME.
c        --- file that gives list of repository elements.
c        --- ROCKS or the TOUGH2 input file which includes ROCKS.
c
c     output files:
c          perch_ele.out ---
c          list of all saturated elements and their water pressure,
c          saturation, material name, bulk volume, and coordinates.
c          perch_ele.rep1 ---
c          list of repository footprint saturated elements, their
c          bulk volume, material name, m & f porosity, and coordinates.
c          perch_ele.rep2 ---
c          list of repository footprint perched elements,
c          and total fracure & matrix water volumes for perched elements
c          identified using the criteria below.
c
c       criterion for perched elements:
c         --- for fractures: water pressure greater than the
c             reference gas pressure: xref.
c         --- for matrix: Pw.gt.xref, and the corresponding fracture
c             element is a perched element.
c
c     note:
c       --- file_inp, file_grid, and file_rocks should be consistent.
c       --- 'vf_tot' contains total water volume in perched-water fracture
c         nodes if the fracture volumes in ELEME are pure fracture space,
c         and in such case 'wf_tot' is meaningless; this is the current
c         setup for the LBNL SR TOUGH2 output.
c         However, if the fracture volumes in ELEME
c         are bulk volumes, then 'vf_tot' contains the
c         total bulk volume, and 'wf_tot' contains total water volume
c         in perched-water fracture nodes.
c
      double precision VOLX
      parameter (xref=0.92e05,z_cut=650.0,z_rep=1100.0)
      character*20 file_inp,file_grid,file_rep,file_rocks
```

```
      character*20 file_out1,file_out2,file_out3
      character elex*5,elen*5,mele*5,eler*5,xele*5,elef*5

c***** input files:
c     write(*,*) 'INCON or SAVE file: file_inp'
c     read(*,'(a20)') file_inp
      file_inp='SAVE.pa_glaL2.dat'
      open(13,file=file_inp,status='old')

c     write(*,*) 'MESH or its ELEME: file_grid'
c     read(*,'(a20)') file_grid
      file_grid='mpa_pch2.v1_ele'
      open(15,file=file_grid,status='old')

c     write(*,*) 'repository elements: file_rep'
c     read(*,'(a20)') file_rep
      file_rep='SR-repo-nodes'
      open(16,file=file_rep,status='old')

c     write(*,*) 'ROCKS: file_rocks'
c     read(*,'(a20)') file_rocks
      file_rocks='pa_glaL2.dat'
      open(17,file=file_rocks,status='old')

c***** output files:
c     write(*,*) 'Output file: file_out1'
c     read(*,'(a20)') file_out1
      file_out1='perch_ele.out'
      open(21,file=file_out1)

c     write(*,*) 'Output file: file_out2'
c     read(*,'(a20)') file_out2
      file_out2='perch_ele.rep1'
      open(22,file=file_out2)

c     write(*,*) 'Output file: file_out3'
c     read(*,'(a20)') file_out3
      file_out3='perch_ele.rep2'
      open(23,file=file_out3)

      open(33,file='tmp.out')

      zmin=20000.0
      vf_tot=0.
      vm_tot=0.
      wf_tot=0.
      wm_tot=0.

      read(13,*)
500   read(13,'(a5)') elex
      if(elex(1:3).eq.'+++') then
          rewind(22)
510       read(22,260,end=570) xele,elen,VOLX,POR,PORF,X,Y,Z
          if(elen(1:1).eq.'F') then
             write(23,'(a5)') elen
             vf_tot=vf_tot+VOLX
             wf_tot=wf_tot+VOLX*PORF
```

```
          else
             rewind(33)
520          read(33,260,end=510) xele,elef
             if(elen(2:5).eq.elef(2:5).and.elef(1:1).eq.'F') then
               write(23,'(a5)') elen
               vm_tot=vm_tot+VOLX
               wm_tot=wm_tot+VOLX*POR
               goto 510
             endif
             goto 520
          endif
          goto 510
570       write(23,*) 'zmin,z_cut,z_rep= ', zmin, z_cut, z_rep
          write(23,*) 'vf_tot,vm_tot= ',vf_tot,vm_tot
          write(23,*) 'wf_tot,wm_tot= ',wf_tot,wm_tot
          write(23,*) 'input files:'
          write(23,'(4a20)') file_inp,file_grid,file_rocks,file_rep
          stop
        endif
        if(elex(1:2).eq.'TP'.or.elex(1:2).eq.'BT') then
          read(13,*)
          goto 500
        endif
        read(13,600) sat_pre,d1,d2,sat_phase
600     FORMAT(4E20.13)

        if(sat_pre.gt.xref) then
          rewind(15)
650       read(15,150,end=800) elen,NSEQ,NADD,mele,VOLX,AHTX,X,Y,Z
150       FORMAT(A5,2I5,A5,2E10.4,10X,3f10.3)
          if(elen.eq.elex) goto 700
          goto 650
700       if(Z.gt.z_cut) then
            if(Z.lt.zmin) zmin=Z
            write(21,200) elex,sat_pre,sat_phase,mele,VOLX,X,Y,Z
200         format(a5,f12.3,1x,f6.4,1x,a5,1x,e15.5,3(1x,f10.3))
          endif

          rewind(16)
          read(16,*)
710       read(16,'(a5)',end=500) eler
          if(elen(3:5).eq.eler(3:5)) then
            rewind(17)
            read(17,*)
            read(17,*)
750         read(17,'(a5)') xele
            IF(xele.EQ.'REFCO'.or.xele.eq.'topbd'
     + .or.xele.eq.'botbd') goto 500
            backspace(17)
            READ(17,210) xele,dx,POR
210         format(a5,5x,2e10.4)
            READ(17,220) PORF
220         format(70x,e10.4)
            READ(17,*)
            READ(17,*)

            if(xele.eq.mele) then
```

```
                write(22,260) xele,elen,VOLX,POR,PORF,X,Y,Z
260             format(2(a5,1x),e11.4,f8.4,e11.4,3f11.3)
                write(33,260) xele,elen,VOLX,POR,PORF,X,Y,Z
                goto 500
             endif
             goto 750
           endif
           goto 710
         endif
         goto 500
800      write(*,*) 'error: no matching element in file_grid!'

         stop
         end
```

(2) Example Input Files:

(a) ‘SAVE.pa_pchL1.dat’
A TOUGH2 SAVE file for the present-day climate, low infiltration, and perched-water model one.

(b) ‘mpa_pch1.v1_ele’
A TOUGH2 ELEME section taken from the mesh file ‘mpa_pch1.v1’, for perched-water model one.

(c) ‘SR-repo-nodes’
A file that gives list of repository elements.

(d) ‘pa_pchL1.dat’
A TOUGH2 input file that includes the ROCKS input section, for present-day climate, low infiltration, and perched-water one.

(3) Example Output File:

pa_pchL1.rep2
List of repository footprint perched elements, and total fracure & matrix water volumes for perched elements within and below the repository footprint, for present-day climate, low infiltration, and perched-water model one.

(4) Verification:

This program has been verified by hand check and visual inspection. As an example, ‘FCi81’ in the output file ‘pa_pchL1.rep2’ is picked up, because the column identifier ‘i81’ exists in the input file ‘SR-repo-nodes’ and the associated hydrologic data (gas pressure = 0.114855e06 Pa, and water saturation = 1.0) in the input file ‘SAVE.pa_pchL1.dat’ indicates this element is under perched-water condition. Its contribution to the total repository-footprint perched-water volume in the fractures is the volume (54.79 m^3) taken from the input file 'mpa_pch1.v1_ele'. Its corresponding matrix element, 'MCi81', is picked up, because, in addition to reasons similar to the above, 'FCi81' has been identified as belonging to perched-water zone. The contribution of 'MCi81' to the total repository-footprint perched-water volume in the matrix is calculated as the product of its element volume (0.3222e06 m^3) taken from the input file 'mpa_pch1.v1_ele' and its porosity (0.288) taken from the input file 'pa_pchL1.dat'.

(5) Output – Table X.1

No.	Case	No. of Nodes	W_f (m^3)	V (m^3)	W_m (m^3)
1	pa_pchL1.dat	121	71459	1.249e07	2.123e06
2	pa_pchm1.dat	654	474417	7.220e07	1.091e07
3	pa_pchu1.dat	727	481183	7.983e07	1.332e07
4	pa_pchL2.dat	268	11306	3.035e07	9.105e06
5	pa_pchm2.dat	1019	44675	1.240e08	3.733e07
6	pa_pchu2.dat	2329	113664	2.958e08	9.165e07
7	pa_glaL1.dat	672	471517	7.221e07	1.108e07
8	pa_glam1.dat	775	508429	8.502e07	1.427e07
9	pa_glau1.dat	838	513904	9.134e07	1.624e07
10	pa_glaL2.dat	846	3800	1.009e08	3.016e07
11	pa_glam2.dat	1475	71464	1.712e08	5.331e07
12	pa_glau2.dat	2493	132378	3.088e08	9.543e07

W_f = total water volume in the fractures of perched-water grid-blocks.
V = total bulk volume of perched-water grid-blocks.
W_m = total water volume in the matrix of perched-water grid-blocks.

Criteria for perched-water condition:
$ For fracture nodes, water pressure is greater than the reference gas pressure.
$ For matrix nodes, water pressure is greater than the reference gas pressure, and the corresponding fracture nodes are in perched-water zone.

Software routine: 'pflux_rep.f'V1

This routine is for calculating the repository-area percolation flux and its histogram (the latter function is not used in the present analysis). Input and output files are explained in the comment section of the program. The code and its output files can be found in the technical database under the data tracking number 'MO9912SPAPWI01.006'. The input files are in 'LB990801233129.001' through 'LB990801233129.012'.

(1) Code Listing:

```
C
C     To produce percolation and percolcation histogram
C     for the repository area.
C
C     Assumption:
C       Vertical connections in the grid are from below to above,
C       i.e., the 1st node is below the 2nd node in a typical vertical
C       connection pair.
C
C     Input Files:
C       SR-repo-nodes --- list of repository nodes.
C       mpa_pch1.v1_conne or mpa_pch2.v1_conne --- connection data.
C       pa_pchL1.out or similar --- TOUGH2 output file.
C
C     Output File:
C       pflux.out --- repository percolations (kg/s, mm/yr).
C

      parameter (ncmax=396770)
      parameter (err_sum_area_frac=0.9999,eps=0.001)
      parameter (rmin_mm=0,rmax_mm=2.0,delt_mm=2.0)
      character*20 file_inp,file_rep,file_conne,file_out
      character block*60, ele1*5, ele2*5, elex*5, elc1*5, elc2*5


c     write(6,*) 'Enter the file name for the TOUGH2 output:'
c     read(5,'(a)') file_inp
      file_inp='pa_pchu1.out'
      open (11,file=file_inp,status='old')

c     write(6,*) 'Enter the file name for repostory nodes:'
c     read(5,'(a)') file_rep
      file_rep='SR-repo-nodes'
      open (12,file=file_rep,status='old')

c     write(6,*) 'Enter the file name for the connections:'
c     read(5,'(a)') file_conne
      file_conne='mpa_pch1.v1_conne'
      open (13,file=file_conne,status='old')

c     write(6,*) 'Enter the output file name for this run:'
c     read(5,'(a)') file_out
      file_out='pflux_rep.out'
      open(21,file=file_out)
```

```
      write(21,*) 'file_inp: ', file_inp

      open(31,file='pflux_rep.tmpf')
      open(32,file='pflux_rep.tmpm')
      open(33,file='pflux_rep.tmpt')

      open(41,file='pflux_rep.ref')

      flux_repf=0.
      flux_repm=0.
      area_rep=0.
      write(41,*) 'conne_pair-flux,rep_ele,conne_pair-area:'
1000  read(11,'(a)') block
      if(block(7:18).ne.'ELEM1  ELEM2') goto 1000
      read(11,*)
      read(11,*)
      num_sumf=0
      num_summ=0
      n1=1
      n2=min(ncmax,53)
      do 1500 i=n1,n2
        read(11,1100) ele1, ele2, flo_liq
1100    format(5x,a5,4x,a5,12x,e13.5)
        if(ele1(1:1).eq.ele2(1:1).and.ele1(3:5).eq.ele2(3:5)) then
          rewind(12)
          read(12,*)
1300      read(12,'(a5)') elex
          if(elex.eq.'+++++') goto 1500
          if(elex(2:5).eq.ele2(2:5)) then
            if(ele2(1:1).eq.'F') flux_repf=flux_repf+flo_liq
            if(ele2(1:1).eq.'M') flux_repm=flux_repm+flo_liq
            rewind(13)
            read(13,*)
1250        read(13,'(2a5,40x,e10.4)',end=1500) elc1,elc2,area
            if(elc1(3:5).eq.elc2(3:5).and.elc2(2:5).eq.elex(2:5)) then
              write(41,1400) ele1,ele2,flo_liq,elex,elc1,elc2,area
1400          format(2a5,e15.5,1x,a5,1x,2a5,e15.5)
              flo=flo_liq*3.1516e07/area
              if(ele2(1:1).eq.'F') then
                num_sumf=num_sumf+1
                write(31,1450) num_sumf,ele2,flo,area
1450            format(i5,1x,a5,2e15.5)
                area_rep=area_rep+area
              endif
              if(ele2(1:1).eq.'M') then
                num_summ=num_summ+1
                write(32,1450) num_summ,ele2,flo,area
              endif
              goto 1500
            endif
            goto 1250
          endif
          goto 1300
        endif
1500  continue

5000  continue
```

```
      if(n2.eq.ncmax) goto 6000
      n1=n2+1
      n2=min(ncmax,N1+56)
      read(11,*)
      read(11,*)
      read(11,*)
      do 4500 i=n1,n2
        read(11,1100) ele1, ele2, flo_liq
4100    format(5x,a5,4x,a5,12x,e13.5)
        if(ele1(1:1).eq.ele2(1:1).and.ele1(3:5).eq.ele2(3:5)) then
          rewind(12)
          read(12,*)
4300      read(12,'(a5)') elex
          if(elex.eq.'+++++') goto 4500
          if(elex(2:5).eq.ele2(2:5)) then
            if(ele2(1:1).eq.'F') flux_repf=flux_repf+flo_liq
            if(ele2(1:1).eq.'M') flux_repm=flux_repm+flo_liq
            rewind(13)
            read(13,*)
4250        read(13,'(2a5,40x,e10.4)',end=4500) elc1,elc2,area
            if(elc1(3:5).eq.elc2(3:5).and.elc2(2:5).eq.elex(2:5)) then
              write(41,1400) ele1,ele2,flo_liq,elex,elc1,elc2,area
              flo=flo_liq*3.1516e07/area
              if(ele2(1:1).eq.'F') then
                num_sumf=num_sumf+1
                write(31,1450) num_sumf,ele2,flo,area
                area_rep=area_rep+area
              endif
              if(ele2(1:1).eq.'M') then
                num_summ=num_summ+1
                write(32,1450) num_summ,ele2,flo,area
              endif
              goto 4500
            endif
            goto 4250
          endif
          goto 4300
        endif
4500  continue
      goto 5000

6000  write(21,*) 'lump fluxes & area for the repository area:'
      write(21,*) 'flux_repf (kg/s),flux_repm (kg/s),area_rep (m*m) ='
      write(21,'(3e15.4)') flux_repf, flux_repm, area_rep
      flux_repf_avg=flux_repf*3.1516e07/area_rep
      flux_repm_avg=flux_repm*3.1516e07/area_rep
      write(21,*) 'flux_repf_avg (mm/yr),flux_repm_avg (mm/yr) ='
      write(21,'(3e15.4)') flux_repf_avg, flux_repm_avg
      write(21,*) 'histogram for f+m fluxes in the repository area:'
      write(21,*) 'No & x0-x1 (mm/yr) & nsamp & freqency & cumulative ='
      rewind(31)
      do 6500 i=1,num_sumf
        read(31,1450) numf,ele1,flof,areaf
        rewind(32)
        do j=1,num_summ
          read(32,1450) numm,ele2,flom,aream
          if(ele2(2:5).eq.ele1(2:5)) then
```

```
            flot=flof+flom
            write(33,1490) numf,ele1,ele2,flot,areaf
1490        format(i5,1x,a5,1x,a5,2e15.5)
            goto 6500
         endif
       enddo
6500  continue

      sum_area_frac=0.
      m=0
7000  m=m+1
      dmm1=rmin_mm+(m-1)*delt_mm
      dmm2=rmax_mm+(m-1)*delt_mm
      area_frac=0.
      rewind(33)
      nsamp=0
      do i=1,num_sumf
        read(33,1490) num,ele1,ele2,flo,area
        if(flo.gt.dmm1.and.flo.le.dmm2) then
          nsamp=nsamp+1
          area_frac=area_frac+area/area_rep
        endif
      enddo
      sum_area_frac=sum_area_frac+area_frac
      write(21,2200) m,dmm1,dmm2,nsamp,area_frac,sum_area_frac
2200  format(i5,2e12.4,i5,2e12.4)
      if(m.gt.200) then
        write(6,*) 'bin interval is too small -> too many bars.'
        stop
      endif
      if(abs(sum_area_frac-err_sum_area_frac).gt.eps) goto 7000

      stop
      end
```

(2) Example Input Files:

(a) ‘SR-repo-nodes’
List of repository nodes.

(b) ‘mpa_pch1.v1_conne’
Connection data taken from the mesh file ‘mpa_pch1.v1’.

(c) ‘pa_pchL1.out’
TOUGH2 output file, for present-day climate, low infiltration, and perched-water model one.

(3) Example Output File:

‘pa_pchL1.pfx’
Repository-area percolation flux and its histogram, for present-day climate, low infiltration, and perched-water model one.

(4) Verification:

This program has been verified by hand check and visual inspection. As an example, the connection 'Frh11Fqh11', its flux '0.10617e-03 (kg/s)' and its interface area '0.18610e05 (m^2)' are picked up from the input files 'mpa_pch1.v1_conne' and 'pa_pchL1.out', because the layer identifier 'q' in combination with the column identifier 'h11' appear in the input file 'SR-repo-nodes'. For similar reasons, the connection 'Mrh11Mqh11' and its associated data are also picked up.

(5) Output – Table X.2

Case	Q_f (kg/s) (fracture flow rate)	q_f (mm/yr) (fracture flux)	Q_m (kg/s) (matrix flow rate)	q_m (mm/yr) (matrix flux)
pa_pchL1.out	0.032	0.206	0.009	0.057
pa_pchm1.out	0.625	4.018	0.080	0.516
pa_pchu1.out	1.800	11.570	0.041	0.260
pa_glaL1.out	0.248	1.593	0.023	0.148
pa_glam1.out	3.030	19.480	0.146	0.936
pa_glau1.out	5.980	38.450	0.075	0.484

Note:

1. Total percolation flux from the repository is dependent on the climate and infiltration scenario only. It has nothing to do with perched-water model, which differs only below the repository. Therefore, only perched-water model 1 is used in this calculation.

2. Q_f and q_f refer to the total fracture percolation flux and average fracture percolation rate from the repository, respectively. Q_m and q_m refer to the total matrix percolation flux and average matrix percolation rate from the repository, respectively.

3. Total area of the repository: 0.4902e07 m^2.

The amount of water released relative to the natural flux through the potential repository can be evaluated by taking the ratio of the volume of water in the fractures of the perched water zone (from Table X.1) and dividing by the total flux rate (volume flow rate for fractures and matrix from Table X.2) through the potential repository. The range of times is shown to range from less than 1 year to 55 years.

Table X.3

No.	Case	W_f (m^3)	$Q_f + Q_m$ (m^3/yr)	Time (yr) $W_f/(Q_f+Q_m)$
1	pa_pchL1.dat	71459	1.29e03	55
2	pa_pchm1.dat	474417	2.220e04	21
3	pa_pchu1.dat	481183	5.81e04	8
4	pa_pchL2.dat	11306	1.29e03	9
5	pa_pchm2.dat	44675	2.220e04	2
6	pa_pchu2.dat	113664	5.81e04	2
7	pa_glaL1.dat	471517	8.55e03	55
8	pa_glam1.dat	508429	1.00e05	5
9	pa_glau1.dat	513904	1.91e05	3
10	pa_glaL2.dat	3800	8.55e03	0.4
11	pa_glam2.dat	71464	1.00e05	0.7
12	pa_glau2.dat	132378	1.91e05	0.7